Dyscalculia in higher education

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DYSCALCULIA IN HIGHER EDUCATION

By

Simon Drew

A Doctoral Thesis

Submitted for the award of Doctor of Philosophy at Loughborough University

September 2015

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Sisyphus by Lacie Cummings
Abstract

This research study provides an insight into the experiences of dyscalculic students in higher education (HE). It explores the nature of dyscalculia from the student perspective, adopting a theoretical framework of the social model of disability combined with socio-cultural theory. This study was not aimed at understanding the neurological reasons for dyscalculia, but focussed on the social effects of being dyscalculic and how society can help support dyscalculic students within an HE context.

The study's primary data collection method was 14 semi-structured interviews with officially identified dyscalculic students who were currently, or had been recently, studying in higher education in the UK. A participant selection method was utilised using a network of national learning support practitioners due to the limited number of participants available. A secondary data collection method involved reflective learning support sessions with two students.

Data were collected across four research areas: the identification process, HE mathematics, learning support and categorisations of dyscalculia. A fifth area of fitness to practise could not be examined in any depth due to the lack of relevant participants, but the emerging data clearly pinpointed this as a significant area of political importance and identified a need for further research. A framework of five categories of dyscalculic HE student was used for data analysis. Participants who aligned with these categories tended to describe differing experiences or coping behaviours within each of the research areas.

The main findings of the study were the importance of learning support practitioners in tackling mathematical anxiety, the categorisations of dyscalculic higher education students, the differing learning styles of dyscalculic and dyslexic students, and the emergence of four under-researched dyscalculic characteristics: iconicity, time perception, comprehension of the existence of numbers that are not whole and dyscalculic students understanding of non-cardinal numbers.

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I would also like to thank everyone within the Mathematics Education Centre for giving me the opportunity to undertake this PhD, and everyone who works there for their invaluable encouragement and assistance throughout this process.

I would also like to thank my family and friends, especially Suzie and Joey for their incredible emotional and practical support throughout my journey, and coping with my many periods of PhD blues. I dedicate this thesis to them.
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- **Mathematical ability**
- **Numerosity and quantification skills**
- **Age appropriateness**
- **Intelligence disparity**
- **Recollection of number facts**
- **Educational and everyday issues**
- **Persistence**

### 3.3.2 Exclusion criteria

- **Educational opportunity**
- **Appropriate motivation**
- **Absence of unrelated impairments**
- **Alternative neurodiversities**
- **Emotional well-being**

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Chapter 1 - Introduction

1 Introduction

1.1 Preface

The picture at the front of this thesis is of Sisyphus, King of Ephyria, who was compelled to carry a large boulder to the top of a mountain. I chose this theme to represent the struggles of a dyscalculic student to achieve their goals in higher education (HE), and how much harder a dyscalculic student may need to work than their peers. Dyscalculia may feel like an extra load holding them back, and evoke a sense of injustice at their plight. Whilst Sisyphus was being punished by the Greek gods for his deceitfulness, dyscalculic students are learning to adapt to a normal variation of the human condition that means that they struggle with mathematics. As I looked at the picture kindly drawn for me by a dyslexic student I was supporting, I noticed that neither the summit nor the base of the mountain could be seen. I realised that for a student with dyscalculia to reach HE they have already been on a long and challenging journey. What the picture does not show is that Sisyphus in this picture is already near the summit, and has travelled many thousands of feet up the mountain defying the gods with his perseverance and strength.

My journey to examining dyscalculia began when studying for my postgraduate certificate of education (PGCE) in secondary mathematics. My cohort was tasked with a small individual research project on any area of mathematics education. I came across an Australian study of how aboriginal children in mainstream schools could be stigmatised as being ‘stupid’ as they performed poorly in class. The study showed that the children were able mathematicians, but struggled to adapt to western teaching styles that did not match the learning environment of their indigenous culture. This led me to consider how individuals learn mathematics differently and how a ‘one for all’ teaching approach may disenfranchise students who need to learn mathematics in a different way.

When I was first introduced to the concept of dyscalculia in HE, I wondered whether students with a neurodiversity also needed to think about mathematics in a manner that was not facilitated by the education system. I became interested in how dyscalculic students can best be supported within HE. I see the end point of this journey as the implementation of new practices to support the mathematical learning needs of dyscalculic students. Before new interventions can be designed, more research is required into how these students learn and comprehend mathematics, and also into the coping strategies which allow them to succeed. For a dyscalculic student to have reached HE and succeeded despite the adversity, they must have already discovered coping strategies that work for them. My PhD, therefore, is about listening to the stories of
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dyscalculic students, trying to understand their difficulties, learning about their coping mechanisms and hearing about their life experiences.

Whilst interviewing one participant in this study, I had an experience that highlighted to me just how mathematics permeates through our everyday lives and how the difficulties of a dyscalculic student go beyond academic work. The participant referred to her sister and as part of a dialogue I asked her how much younger her sister was. This was purely conversational and I had not considered the mathematical ramifications of the question. The student paused, deliberated, and replied, "she’s at GCSE age”, thus answering my question appropriately, whilst cleverly avoiding the mathematical task I had inadvertently set her to subtract her sister’s age from her own age. This moment showed me how often we refer to mathematics without thinking about it, and how a dyscalculic student can never successfully avoid mathematics completely as it so embedded in our daily lives.

1.2 Background

Dyscalculia is a specific learning difference (SpLD) that “affects the ability to acquire arithmetical skills. Dyscalculic learners may have difficulty understanding simple number concepts, lack an intuitive grasp of numbers, and have problems learning number facts and procedures. Even if they produce a correct answer or use a correct method, they may do so mechanically and without confidence” (Department for Education and Skills (DfES), 2001, p2). With developing awareness of dyscalculia and increasing numbers of students being officially identified, there is an expectation from students, teachers and learning support staff that suitable support is available across all levels of education.

The mathematics learning support centre (MLSC) at Loughborough University, in aiming to provide support for dyscalculic students, has encountered a knowledge gap. There has been negligible research published into how adult dyscalculic learners should be supported, and no one has yet addressed any specific issues that arise from higher education (HE). Currently dyscalculia research is focussed on neuroscience and early years’ learning.

Networking opportunities with other HE learning support staff revealed that this problem is widespread, with anecdotal evidence that strategies known to be effective with dyslexic students are offered on a ‘try it and see if it is useful’ basis, with no academic research to show whether these strategies are applicable or beneficial to dyscalculic students. Little is understood of the mechanics via which dyscalculic HE students learn mathematics, the difficulties they encounter, or the coping strategies that they may have developed independently.
1.3 Research questions

There are four research questions that are addressed by this study:

- **What are the experiences of dyscalculic students in HE that lead to the identification of dyscalculia?**
- **What are the experiences of mathematics of dyscalculic students in HE?**
- **What are the experiences of learning and support of dyscalculic students in HE?**
- **Are there different categories of dyscalculic student in HE?**

At the start of the study, dyscalculic students’ childhood, everyday and workplace experiences were also considered. However, the amount of data became too large and the scope was reduced for reasons of manageability. The four remaining research questions focus upon the academic experience of HE. They explore the identification process from the viewpoint of the dyscalculic students, and then examine how the dyscalculic students perceive mathematics, learning and support within HE. The final question asks whether dyscalculic students are similar, unique or display characteristics that form identifiable categories. Occasionally examples from outside of HE have been used when they are pertinent.

One of the difficulties with presenting the data in this study was that of breadth versus depth. My study revealed plenty of rich and diverse data which I found difficult to focus. There are many areas that could have been explored more deeply, to the detriment of other important areas of information. This work attempts to achieve a compromise between capturing as much data as possible, whilst still allowing for the necessary academic analytical depth required of a doctoral thesis.

1.4 Outline of thesis

After the introductory chapter, the theoretical work that forms the framework of the study is discussed to clarify the theoretical perspective before the literature review. This is especially important for understanding the concept of the social model of disability, which is fundamental throughout the thesis.

The literature review is split into three parts, chapters three to five, which cover dyscalculia, neurodiversity and higher education respectively (see figure 1). The history of dyscalculia research and current theories as to its nature and prevalence form the main focus of the literature review, but to better understand dyscalculia, knowledge of
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the domain of neurodiversity, of which it forms part, is necessary. As this study looks explicitly at how dyscalculia affects students in HE, knowledge of the existing HE learning support process for students with neurodiversity is also required.

Figure 1 – Domain of literature review

The next two chapters (6-7) describe how the research process took place. Chapter six describes the methodology utilised, which includes the overarching approach and data collection and analytical methods employed. Chapter seven charts the implementation of the research methodology, which covers sample selection, and the resulting data codes created by my analytical process.

The next five chapters (8-12) form the results and discussion of my thesis. Chapters eight through to eleven address each one of the four research questions posed. Each of these chapters culminates in a summary and discussion of the findings. The twelfth chapter considers an issue known as fitness to practise, which was not part of my initial research questions, but was such a strong theme to emerge that I felt it needed to be addressed.

Finally, chapter thirteen forms the conclusion to my study, and is followed by related work, references and appendices.
## 1.5 Glossary of terms

The following terms and abbreviations included in table 1 are used throughout the thesis.

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD(H)D</td>
<td>Attention Deficit (Hyperactivity) Disorder</td>
</tr>
<tr>
<td>ADSHE</td>
<td>Association of Dyslexia Specialists in Higher Education</td>
</tr>
<tr>
<td>Assessment</td>
<td>The process to officially identify an individual with a specific learning difference (SpLD). Must be performed by a qualified practitioner, usually an Educational Psychologist (EP).</td>
</tr>
<tr>
<td>BDA</td>
<td>British Dyslexia Association</td>
</tr>
<tr>
<td>Cardinality</td>
<td>A mathematical term to denote the number of objects in a collection. Can also refer to the size of a continuum, e.g. how much water</td>
</tr>
<tr>
<td>CDD</td>
<td>Co-occurrence of Dyscalculia and Dyslexia category</td>
</tr>
<tr>
<td>DSA</td>
<td>Disabled Students Allowance</td>
</tr>
<tr>
<td>DSM</td>
<td>Diagnostic and Statistical Manual of Mental Disorders</td>
</tr>
<tr>
<td>DWN</td>
<td>Dyscalculic With Numerosities Issues category</td>
</tr>
<tr>
<td>DWO</td>
<td>Dyscalculic Without Numerosities Issues category</td>
</tr>
<tr>
<td>DYO</td>
<td>Dyscalculia Only category</td>
</tr>
<tr>
<td>EP</td>
<td>Educational Psychologist</td>
</tr>
<tr>
<td>FE</td>
<td>Further Education</td>
</tr>
<tr>
<td>HAch</td>
<td>High Achiever category</td>
</tr>
<tr>
<td>HAnx</td>
<td>Highly Anxious category</td>
</tr>
<tr>
<td>HE</td>
<td>Higher Education</td>
</tr>
<tr>
<td>HEI</td>
<td>Higher Education Institution</td>
</tr>
<tr>
<td>MA</td>
<td>Mathematical Anxiety (or Mathematics Anxiety)</td>
</tr>
<tr>
<td>Manipulatives</td>
<td>Resources designed for kinaesthetic learning, such as building blocks, connecting links, marbles and coins.</td>
</tr>
<tr>
<td>MD</td>
<td>Mathematics difficulties</td>
</tr>
<tr>
<td>MDY</td>
<td>Moderately Dyscalculic category</td>
</tr>
<tr>
<td>MEC</td>
<td>Mathematics Education Centre</td>
</tr>
</tbody>
</table>
Chapter 1 - Introduction

<table>
<thead>
<tr>
<th>Medical model (of disability)</th>
<th>A socio-political model whereby disability is seen as the result of a physical condition of an individual.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLD</td>
<td>Mathematics learning difficulties</td>
</tr>
<tr>
<td>MLSC</td>
<td>Mathematics Learning Support Centre</td>
</tr>
<tr>
<td>Multisensory</td>
<td>Learning that is related to several bodily senses.</td>
</tr>
<tr>
<td>Neurodiverse</td>
<td>A cognitive profile with a neurological difference.</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>An approach to learning and disability that suggests that neurological conditions are a normal variation of the human brain.</td>
</tr>
<tr>
<td>Neurotypical</td>
<td>A cognitive profile that does not pertain to any known neurological difference.</td>
</tr>
<tr>
<td>NMC</td>
<td>Nursing and Midwifery Council</td>
</tr>
<tr>
<td>Number fact</td>
<td>A memorised number property such as number bonds or multiplication tables.</td>
</tr>
<tr>
<td>Numerosity</td>
<td>A neuroscience term for cardinality. Within the scope of this thesis the two terms are synonymous.</td>
</tr>
<tr>
<td>PGCE</td>
<td>Postgraduate Certificate of Education</td>
</tr>
<tr>
<td>RA</td>
<td>Reasonable Adjustments</td>
</tr>
<tr>
<td>QTS</td>
<td>Qualified Teacher Status</td>
</tr>
<tr>
<td>SA</td>
<td>Statistical anxiety (or statistics anxiety)</td>
</tr>
<tr>
<td>Screening</td>
<td>An initial process to help identify individuals who are likely to have an SpLD. The result of this does not form an official identification.</td>
</tr>
<tr>
<td>SDY</td>
<td>Severely dyscalculic category</td>
</tr>
<tr>
<td>Social model (of disability)</td>
<td>A response to the medical model of disability, this model claims that society is the main contributory factor in disabling individuals when it fails to provide provisions for individuals with a disability or neurodiversity.</td>
</tr>
<tr>
<td>SpLD</td>
<td>Specific learning difference – an umbrella term that refers to dyslexia, dyspraxia, dyscalculia and dysgraphia</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, technology, engineering and mathematics</td>
</tr>
<tr>
<td>Subitising</td>
<td>The rapid and accurate judgment of small number quantities without counting</td>
</tr>
<tr>
<td>ZPD</td>
<td>Zone of proximal development</td>
</tr>
</tbody>
</table>

*Table 1 – Glossary of terms*
Chapter 2 - Theory

2 Theory

2.1 Introduction

A theoretical perspective, or framework, is a stated acknowledgement of pre-existing theories that have shaped research design and influenced interpretation of the results of a study (Crotty, 1998). Schwandt (2000) described how the interpretation of results is wholly dependent on a researcher’s theoretical stance, and therefore this must be openly acknowledged:

As one engages in the ‘practical’ activities of generating and interpreting data to answer questions about the meaning of what others are doing and saying and then transforming that understanding into public knowledge, one inevitably takes up ‘theoretical’ concerns about what constitutes knowledge and how it is to be justified, about the nature and aim of social theorizing, and so forth. In sum, acting and thinking, practice and theory, are linked in a continuous process of critical reflection and transformation (p190).

I discuss existing theories about the nature and causes of dyscalculia and other specific learning differences in chapters three and four. This section provides an overview of socio-cultural theory, the key theory of learning underpinning this research, and the social model of disability, which recognises the negative attitudes and systematic barriers created by society that may exclude disabled and neurodiverse individuals from cultural activities. These two complementary perspectives frame how engagement in social practice is necessary for all students to maximise their learning potential, and how societal practices do not always provide allowances for dyscalculic students, restricting their access to this optimum learning environment.

2.2 Epistemology

Epistemology is a philosophy that defines the nature of knowledge, with specific regard to its methods, scope and validity (Collins English Dictionary, 2013). Within education research, the epistemological stance of the researcher will match the theory of learning adopted as part of the theoretical framework (see section 2.3), otherwise a contradiction would exist. My chosen epistemological position is that of socio-cultural theorist; the accumulation of knowledge is not an individualised mental construction based upon personal interactions with the world (constructivism), but part of a “culturally mediated, historically developing, practical activity” (Cole, 1998, p108). Cobb (2009) described socio-cultural learning as a “process by which people develop particular forms of reasoning as they participate in established cultural practices” (p18).
My research questions focus upon the nature of dyscalculia according to the life experiences of dyscalculic students. I had no expectation that these experiences would be uniform as may be suggested by an objectivist epistemological stance, but envisaged that each student had created personalised meaning regarding their neurodiversity that had been informed by shared cultural experiences in the classroom, learning support centre, workplace or everyday life.

### 2.3 Theoretical perspective

Historically, theoretical perspectives pertaining to education have drawn upon theories of learning, including cognitive theory (Bruner, 1966), behaviourism (Skinner, 1960; Greene & Hicks, 1984; Wheldall et al., 1989), constructivism (Dewey, 1933; Piaget, 1977; Glasersfeld, 1996) and social-based learning theories such as social constructionism (sometimes referred to as social constructivism) (Gergen, 1985; Burr, 2003) and socio-cultural theory (Vygotsky, 1978; Leontyev, 1981; Engeström, 1987). Social-cultural theories lend themselves well to the overarching philosophy of the social model of disability, as there is a dual emphasis on how social interaction and community impacts on the learner.

Numerous authors have considered research in mathematics education from the perspective of socio-cultural theory (Cobb et al., 1996; Lerman, 1996; Roth, 2003; Williams et al., 2009). However, research around dyscalculia has generally been conducted within a positivist medical model framework (Geary, 2004; Landerl et al., 2004; Butterworth, 2005a). I am unaware of any socio-cultural studies that examine dyscalculia, although there has been a precedent set with dyslexia where Pollak (2005) employed social constructionism to explore how students construct their own sense of identity from their socially-embedded experiences that result from being dyslexic. Social constructionism is an umbrella term that opposes positivism and dictates that reality is a construct as a result of social interactivity (Nightingale & Cromby, 1999). Although Pollak used a different theoretical perspective to my own, his choice was suited to his focus on identity, whereas my research questions are aimed at social experiences of learning. The two perspectives although different are compatible as Pollak stressed the social impact upon his participants and that their dyslexic identities were formed by attempting to take part in socio-cultural activities and were not formed by mere observation. Unlike constructivism which Gergen (1995) criticised as being too ‘interiorised’, social constructionism focuses on "relational, conversational, social practices as the source of individual psychic life" (Stam, 1998, p199).
Whilst Pollak’s approach provided a valuable insight into a neurodiverse student’s sense of identity, the focus was on the individual rather than on learning as a social process. As this research aims to address gaps in the knowledge base and inform future teaching practice, I have considered the dyscalculic student within the wider social and educational context. Socio-cultural theory provides a vehicle with which to explore the student’s learning processes and how they are influenced by social interactions. Vygotsky (1978) described a cognitive construct called the inter-psychological plane, which is learning dependent upon interaction with other people within a shared culture, such as the classroom, lecture theatre, group work, or mathematics-rich everyday activities such as shopping or sports. The assimilation of this internalised knowledge into a personal expression of meaning, the intra-psychological plane, is not just a knowledge transfer, but a transformational process that creates personalised values and mental constructs (Vygotsky, 1978). For dyscalculic students this represents not just a sense of mathematical identity, but the interpretation of mathematical meaning and the formation of individualised strategies for tackling mathematical challenges, drawn from the students’ cultural experiences, both inside and outside of a traditional educational setting.

Socio-cultural theory focuses on the interaction between learners and the cultural context. Wertsch (1991) described a socio-cultural approach to qualitative social research as the creation of accounts of human mental processes that “recognise the essential relationship between these processes and their cultural, historical, and institutional settings” (p6). Lave and Wenger (1991) described the motives of socio-cultural theorists as:

*Rather than asking what kind of cognitive processes and conceptual structures are involved, they ask what kinds of social engagements provide the proper context for learning to take place* (p14)

This research aims to explore what dyscalculia means to the participants, the dyscalculic students. This meaning is not only socially driven, but has been ‘externalised’ into the environment and can be seen when the neurodiverse students target their anger over being dyscalculic. Rather than blame the neurodiversity, they find various targets within their social world towards which they address their anger: unsympathetic teachers, lack of learning support or late identification. An understanding of how each participant views their own neurodiverse experience was needed to form a broader picture of how dyscalculic students learn and can be best accommodated within higher education. Meaning is “central to the socio-cultural approach of mediated action” (Wertsch, 1991, p67) and Meretz (1999) claimed that “meanings arise from societal production of use-
value" (p126), highlighting the importance of using a socio-cultural framework to interpret the results.

My research has drawn upon particular contributions to socio-cultural theory that I felt best matched the dimensions of my research domain: dyscalculia, neurodiversity, mathematics learning and higher education. I have chosen to incorporate Vygotsky’s (1978; 1986) work on the zone of proximal development (ZPD) and mediated actions.

I have also drawn strongly upon the theories of two dyslexia researchers as I explain below. Pollak (2002) performed a similar PhD study to my own when looking at the experiences of dyslexic HE learners, although his scope was narrower in exploring only dyslexic identity by the use of discourse analysis. Chinn and Ashcroft (1998) described two types of mathematical learner, the grasshopper and the inchworm, which appeared to share similarities with the difference between how dyslexic and dyscalculic students learn mathematics. This is discussed in section 10.2.1 when examining learning styles. I also introduce the concept of the Stroop effect, which is a cognitive theory related to visual perception that has been shown to be related to dyscalculia.

2.3.1 Vygotsky and socio-cultural theory

Socio-cultural research is rooted in the works of Vygotsky, who explored how actions are mediated by physical artefacts, procedures or language, known as tools. The ability to craft tools has been a significant factor in the evolution of humanity, and their anthropological importance can be tracked from the creation of flint weapons through to the computerisation of the modern world. Vygotsky (1978) introduced the concept of the mediated action, where a task has been facilitated by the use of a physical or conceptual tool, which facilitates the creation of new meanings within the environment (Yamagata-Lynch, 2010). Tools that may be used to perform mathematical tasks could be physical, for example a calculator or ruler, or conceptual such as an arithmetic strategy, mathematical procedure or learning support process. Exploration of how these tools differ for dyscalculic students has offered an insight into the nature of dyscalculia as a neurodiversity. Traditional tools are often ineffective for dyscalculic learners, so in order to improve future teaching practice and inform learning support strategies it is important to identify the tools which dyscalculic students have created for themselves, or with support from tutors, to successfully mediate mathematical tasks. These strategies have been developed outside of the traditional teacher/classroom educational process, but socio-cultural theory tells us that these strategies have not been developed in isolation, but as a result of the dyscalculic student’s experienced world. Socio-cultural theory provides a lens for observing how these coping strategies function, by considering how
the activity of performing mathematical tasks has been modified to allow the activity to become viable. This is in contrast to when a dyscalculic student struggles with an unmediated mathematical activity or an activity mediated with inappropriate tools.

Tools are influenced by culture, and in turn influence both the subject and the structure of activity and provide the path for the accumulation and transmission of social knowledge (Daniels, 2008). These tools are ‘exteriorised’ forms of mental processes, and as they are manifested, they become more readily accessible and communicable to other people, thereafter becoming useful for social interaction (Vygotsky, 1978). By examining coping strategies I have therefore been able to better understand the interiorised mental processes that dyscalculic students have when encountering mathematical tasks. The manner in which coping strategies are formed and their inherent purpose illuminates how a particular mathematical challenge is perceived by the dyscalculic students. This is where the study of higher education students has been particularly beneficial; as adults, the students are able to articulate their feelings and describe which strategies have been successful (or serendipitous), to overcome the barriers created by their neurodiversity and the educational system, in order to reach tertiary education.

The individual’s relationships with mediating tools are not constant, but evolve over time (Vygotsky, 1978). The pattern of how dyscalculic students create and modify these coping strategies over time can give clues as to the trigger events that led to the most successful mediation of mathematical challenges. If social practice could be changed to provide a more fertile landscape for dyscalculic students to develop their own coping strategies, then the mediation of tools as described by Vygotsky could happen sooner and more effectively.

Scribner, the co-editor of Vygosky’s seminal *Mind in society: The development of higher psychological processes*, described how individuals do not passively wait for the world to confer meaning to them; instead they create their own meaning by creating and modifying activities that in turn cause transformations of the tools themselves and the people within their environment (Scribner & Tobach, 1997). The meaning of mathematics is a crucial concept in dyscalculia research. As the dyscalculic students are unable to conceptualise mathematical ideas in the same manner as neurotypical students, they create alternative constructs to offer meaning and provide a framework for addressing mathematical issues. An example of this is how the dyscalculic students in the study perceive ‘understanding mathematics’ as being able to follow procedural tasks, and define mathematical achievement as the ability to produce correct answers, even if they have no conceptualised understanding of the task or what they have been asked to perform.
Figure 2 – 1st generation activity theory

Figure 2 shows the Vygotsky mediated action triangle. In this model an activity is the engagement of a subject toward a particular goal or objective. The subject is the individual or group engaged in the activity. The object is the goal needed to achieve the desired outcome. Kuutti (1996) defined activity as "a form of doing directed to an object" (p27) and went on to argue that transforming the object into an outcome by engaging with it through mediating tools, motivates the existence of an activity. Schaffer (2004) criticised Vygotsky in that he did not consider the individual’s desire to learn, but motivation has been addressed by other socio-cultural theorists (Lave & Wenger, 1991; Sivan, 1986; Hickey & Zuiker, 2005). An understanding of emotional drivers to overcome educational barriers is paramount to revealing the participants ‘sense of mathematical identity’.

Another socio-cultural concept, the ‘zone of proximal development’ (ZPD) was defined as:

\[
\text{The distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers (Vygotsky, 1978, p86).}
\]

Vygotsky (1978) stated that provision of appropriate support can enhance a student’s learning to a level that would be otherwise unattainable. The domain spanning that which can be achieved, with and without that support, is defined as the ZPD (Vygotsky, 1978). This concept of supervisory assistance has since become synonymous with the
term ‘scaffolding’ (Wood et al. in 1976). Scaffolding theory was originally developed within cognitive psychology to describe the acquisition of language skills, with Bruner (1978) describing scaffolding as a cognitive support mechanism given by teachers or peers to enable students to complete tasks that would otherwise be beyond their current capabilities. He went on to describe this scaffolding process as "vicarious consciousness" (Bruner, 1986, p72). Scaffolding and Vygotsky’s ZPD explain how learning takes place within a cultural framework, notably in educational contexts.

While Vygotsky himself was mostly concerned with learning/teaching in school, recent research has extended his ideas to a wider range of mental functions, ages, and settings (Wertsch, 1984). In this study, the ZPD is used as a theoretical perspective to explore the existing learning support that dyscalculic students receive. By identifying those teaching or support practices that facilitate progress through this zone, future interventions could be developed to enhance learning support opportunities. Learning support is often delivered on a one-to-one basis, which is an example of scaffolding in action, as tutors are able to adapt their support to meet the needs of individual students. The ZPD has allowed me to focus on the nature of this support, and the potential of each student.

2.3.2 Social model of disability

The social model of disability, which I will refer to as the ‘social model’, originated from disability activists in the 1970s and was given academic credibility by Finkelstein (1981) and Oliver (1990). The British disability movement referred to the social model of disability as ‘the big idea’ (Hasler, 1993). British disability politics use this model as a framework to "distinguish between organisations, policies, laws and ideas which are progressive and those which are inadequate" (Shakespeare & Watson, 2002, p11).

The social model makes a distinction between impairment and disability. It defines impairment as a medical issue or difference of an individual, and disability as a social construct that prevents the individual from participating in everyday life (Oliver, 1990). The social model examines the ways that barriers faced by people with disabilities can be removed to facilitate full societal participation as equal and independent citizens. Oliver (1992) claimed that:

Disability cannot be abstracted from the social world which produces it; it does not exist outside the social structures in which it is located and independent of the meanings given to it (p101).
This is in contrast to the medical model of disability that concentrates on the impairment as the cause of the disability. Both models aim for the eradication of disability, but focus on a different domain. A useful analogy is that of the wheelchair user unable to enter a library. The medical model would concentrate on the reasons why walking was not possible, possibly due to loss of limbs or paralysis. The social model would instead focuses on the lack of ramps and wheelchair access that prevents the wheelchair user having independent access to the library.

Oliver’s original theory was from a materialist, Marxist perspective, where a capitalist society was the cause of oppression against individuals with impairments, and inclusivity could only be achieved by normalisation. The social model has since evolved and fragmented, and I have chosen to adopt a less deterministic version of the theory developed by researchers such as Shakespeare (2013) who have employed a perspective of ‘critical realism’. Shakespeare argued that the social oppression argument can not explain all aspects of disability, for example pain is part of the experience of many individuals’ impairment, but cannot be blamed on society’s lack of inclusivity. Shakespeare (2002) felt that impairment and disability are not dichotomous, but a continuum, and support at both the medical and social level should be considered to improve the individual’s life experience. He claimed that "intervention at physical, psychological, environmental and socio-political levels is the key to progressive change, yet one cannot be a substitute for the other" (p25).

My use of the social model will take a stance that is more aligned to Shakespeare’s ideological position, where I believe that society has a responsibility to evolve to be more inclusive, but equally I believe that impairment can be justifiably considered as both a medical and social construct, and the alleviation or removal of disability can be achieved by either approach, or a combination of approaches.

The social model has been used previously with studies involving dyslexia. Barbara Riddick (2001) explored the effect of school literacy standards on limiting the achievements of dyslexic students, and questioned the imbalance of articles on dyslexia, with most focussing upon cognitive theories or educational issues rather than the “social and personal consequences” of dyslexia (2009, p1). Mortimore (2008) also used a social model perspective to examine classroom strategies that aid dyslexic learners and support inclusivity. Macdonald (2009) claimed that the size of any disabling barriers is related to social class status, as working class students have less access to enabling resources such as specialist teaching or technology. He later argued that a social model based approach that focussed on the disabled students’ rights was required to remove existing educational barriers (2013). Pollak (2002) made a significant contribution to the
field of dyslexia studies by applying the social model to his 2005 PhD study of dyslexic
students in higher education. This thesis and subsequent book in 2005 form a part of my
theoretical framework (see section 2.3.3).

This theoretical perspective emphasises my interest in the participants’ stories of living
with dyscalculia, as opposed to medical explanations as to the cause of the
neurodiversity. I have analysed the narratives from a perspective of participants being
unable to reach their full academic potential due to social and academic barriers. The
data has not only identified where these barriers have occurred, but whether the
dyscalculic students recognise these barriers and consider that they have been
discriminated against.

Disadvantage (archaically referred to as a ‘handicap’) experienced by an individual is a
function of both disability and requirement (Hutchison, 1995). Therefore a disadvantage
would not exist if the individual was undertaking a task where their impairment had no
impact. The social model is appropriate in examining how a disadvantage can be reduced
by limiting the effect of a disability in a particular situation. This could involve such
provisions as accessibility ramps or one-to-one support.

When considering specific learning differences, the social model of disability can be used
in conjunction with Vygotsky’s work (see section 2.3.1) as they both examine issues
from a societal perspective. These two theories express how positive social interaction is
important to aid self-development and support the achievement of an individual reaching
their full potential. Socio-cultural theory assumes that learning is best accomplished as a
shared experience embedded within communal practice, a concept which aligns to the
social model of disability’s focus on how adapting social expectations and structures can
enhance the potential of neurodiverse learners to overcome their disadvantage.

2.3.3 Pollak and dyslexic identity

In Pollak’s 2002 PhD study of dyslexic HE students he used discourse analysis to
categorise how the participants referred to themselves. He found evidence of four
categories which the participants felt aligned to: patient, hemispherist, student and
campaigner. A fifth category, syndromist, was described in smaller quantities, but was
not adopted by any of the participants.

In this model, Pollak (2002) found that all his sample students began with a
categorisation of patient, where they considered that they had a medical condition and
used language that described ‘something wrong’ with them. Pollak’s hemispherist
category was used to describe how a dyslexic learner recognises the ‘spiky profile’ of
their neurodiversity and accepts that difficulties can be counterbalanced by abilities. Research has shown that dyslexic individuals often have greater than average visual and creative skills, creating a profile of cognitive strengths and weaknesses (West, 1997).

Pollak’s third category was *student*, where the participant did not appear to refer to him or herself as someone with a neurodiversity, but was more focussed on their life as an HE student. The *campaigner* category described situations where the participant experienced a sense of injustice at how they had been treated by society due to their dyslexia. The fifth category of participant mentioned by Pollak was *syndromist*, describing those who would identify with a set of difficulties, rather than with a label of a particular neurodiversity. The name stems from Singleton’s description of dyslexia as “a syndrome: a collection of associated characteristics that vary in degree and from person to person” (Singleton, 1999, p25). Pollak found that this category was alluded to by several participants, however they had all aligned more strongly with alternative categories, resulting in Pollak excluding *syndromist* from his final model (see figure 3). The sizes of the boxes in the Pollak diagram are an approximation of the prevalence of participants found in each category, based upon 33 dyslexic students.

Pollak also theorised how dyslexic students may progress from one category to the next as they come to understand their neurodiversity over time. He described participants starting with the *patient* category, and then progressing through to more social model-

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*Figure 3 – Pollak model of category transition for dyslexic HE students*
based categories, with some eventually reaching campaigner. Note that Pollak saw campaigner as the most progressive category in his model, which was not necessarily the same in my study (see section 11.2.4).

2.3.4 Conceptual and procedural mathematical learning styles

Sections 2.3.4 and 2.3.5 explore two theories of mathematics education that have been incorporated into previous research into dyscalculia, which I also use to frame my research.

The first theory incorporates the idea of two contrasting styles for learning mathematics: conceptual and procedural. This has been an important topic of mathematics education for many years, although the terminology has evolved (Hiebert, 1986). Piaget (1978) referred to conceptual understanding and successful action whilst Anderson (1982) referred to declarative and procedural knowledge.

Conceptual knowledge can be defined as "a connected web of information in which the linking relationships are as important as the pieces of discrete information that are linked" (Goldman & Hasselbring, 1997, p4). Procedural knowledge can be defined as the ability to follow rules and algorithms to solve a mathematical task, with each instruction performed in a predetermined linear sequence (Carnine, 1997).

Chinn and Ashcroft (1998) described two types of mathematical learner, the grasshopper and the inchworm, which are metaphors for conceptual and procedural understanding. A ‘grasshopper’ sees mathematics holistically, has an intuitive approach due to a sound conceptual understanding of the underpinning principles of mathematics and is able to tackle problems in various formats. They may, however, struggle to document their workings and be prone to careless errors. An ‘inchworm’ conversely prefers a sequential stepwise approach to tackling mathematical problems, and will usually be able to follow a prescribed method. An ‘inchworm’ may have little understanding of the mathematics involved and struggle to adapt their approach to different scenarios. They do, however, document their work well and are generally thorough and precise.

The descriptions described by Chinn and Ashcroft match closely the differing mathematical learning styles adopted by many dyslexic (grasshopper) and dyscalculic (inchworm) learners (see section 10.2.1). This is not to say that a dyslexic or dyscalculic student will always display this learning style however these methods align with the neurodiverse strengths of the dyslexic and dyscalculic student respectively.
2.3.5 Stroop effect

The second mathematics education theory is the Stroop effect which is a cognitive phenomenon that has been shown to have a significant impact on dyscalculic students (Butterworth, 1999), and is discussed at various points throughout this thesis. This is when reaction time of performing a task is increased due to unrelated visual information that the reader incorrectly perceives as relevant. It was proposed by John Stroop in 1935 when he discovered that if a colour was written in a font of a different colour, e.g. ‘blue’ written in red, the word takes longer to read and is more prone to error. The Stroop effect has also been used with numbers, by displaying digits of different sizes and asking the reader to state which is numerically larger. The physical size differential of the digits increases the calculation time in making the judgement.

2.4 Summary

This chapter introduced the previous theoretical work, outside of dyscalculia (see chapter 3) and other neurodiversities (see chapter 4), that has informed this research. It defined the two theoretical perspectives, socio-cultural theory and the social model of disability, which provide the framework for this thesis. I referenced previous works from Pollak, Chinn and Ashcroft which have produced models of learning that are used to provide a framework to analyse my data. Finally I considered the Stroop effect, which is currently used in dyscalculia screeners, and provides a possible explanation for some of the characteristics observed in this thesis.
Chapter 3 - Dyscalculia

3 Dyscalculia

3.1 Introduction

In this chapter I explore the history of dyscalculia, and examine the most high-profile definitions, discussing how they have evolved as research has progressed. I then critique these definitions to draw out the essential elements of dyscalculia.

Dyscalculia is a neurodiversity which affects the ability to acquire arithmetical skills (Department for Education and Skills (DfES), 2001). Researchers have been trying to understand the nature of dyscalculia since Kosc (1974) first imbued the term with its current meaning, and have since created a variety of definitions to establish the criteria required for identification.

Research papers on dyscalculia cite various figures for prevalence, but it is often unclear from where these figures have originated. I follow these citations to their source to find the papers that first described the experiments that deduced these prevalence statistics. This analysis allows for a comparison of results and leads to a discussion on how the author’s chosen definition of dyscalculia has affected the results.

The chapter then describes the characteristics of dyscalculia, listing the difficulties that dyscalculic individuals may have during education and everyday life. This is the evidence from which dyscalculia could be identified during screening or assessment. I have gathered this data from both research studies and anecdotal reports from learning support practitioners. A section is dedicated to the relationship between dyscalculia and time as this was found to be a significant issue within my sample group.

For background completeness, the concluding sections of this chapter look briefly at dyscalculia from a cognitive perspective. I summarise some of the latest thinking, but have chosen not to explore this domain in great depth as this thesis does not attempt to focus on the causes of dyscalculia, but on how dyscalculic students can be supported. As this research is not based on the medical model, I have not included a section on neuroscience, although there is some background information in appendix M.

3.2 History of dyscalculia

The word dyscalculia has its etymological roots from the term ‘acalculia’ coined by Henschen in 1925 to refer to cases of mathematical impairment caused by head injury. This is the same way the name dyslexia originated, stemming from the earlier term alexia (Aaron et al., 1980; Bub, 2003).
Dyscalculia as a word was first suggested by Gerstmann in the 1940s to describe an "isolated disability to perform simple or complex arithmetical operations and an impairment of orientation in the sequence of numbers and fractions" (Alexander & Money 1966, p286), as part of his early research into a separate and rare neurological disorder now known as Gerstmann’s Syndrome (Gerstmann, 1940). The term dyscalculia was then adopted by mathematics researchers to describe difficulties with age-appropriate arithmetic tasks (Bakwin & Bakwin, 1960; Cohn, 1968), but these investigations did not distinguish mathematical difficulty from other cognitive issues such as poor general intelligence or other specific learning differences; any individual who struggled with mathematics could have been described as dyscalculic.

In 1974 Kosc considered dyscalculia to be "a much more complicated disorder" (p165) than previously described and recognised that it is a developmental mathematical learning difficulty that is independent of general intelligence (Kosc, 1974). Kosc claimed that there were six subtypes of dyscalculia, which he categorised as lexical (reading symbols), graphical (writing symbols), verbal (articulating mathematics), ideognostic (conceptual understanding), practognostic (application of mathematics), and operational (arithmetic). Some of the subtypes observed by Kosc, such as lexical and graphical, would today be more likely attributed to dyslexia with mathematical difficulties (see section 4.3.1), or dyspraxia (see section 4.3.2), rather than dyscalculia in isolation. Of particular interest is Kosc's ideognostic dyscalculia, which he described as a difficulty in "understanding mathematical ideas" (p168) and forming mental number relationships, e.g. that nine is one less than ten. It was not until a quarter of a century later that this "lack of a true comprehension or understanding of maths" was recognised as the key characteristic of dyscalculia (Chinn, 2006, p15).

The American Psychiatric Association, a provider of classifications of mental health issues by means of the publication Diagnostic and Statistical Manual of Mental Disorders (DSM), was one of the first official medical bodies to recognise the existence of a ‘mathematics disorder’. Although originally designed for use in the United States, the DSM has increasingly been recognised as the global standard and has become the source most referenced by educational psychologists. In the 1960s the DSM began to include categorisations of learning differences (American Psychiatric Association (DSM-II), 1968), and in the third edition in 1980 the DSM introduced the idea of a "developmental arithmetic disorder" (American Psychiatric Association (DSM-III), 1980). Although the definition did not use the term dyscalculia, it had strong similarities to Kosc's definition, despite using language more accessible to a non-neuroscientist. The definition also described how this neurodiversity may affect academic and everyday life. Here, the social model perspective was seen for the first time within a dyscalculia definition, as the
quality of life of the individual was deemed an important factor in establishing identification. By acknowledging real-life everyday issues, focus began to centre on the need for social barriers to be overcome. The last major revision of the DSM was the fifth edition, published in 2013 (American Psychiatric Association (DSM-5), 2013) which now recognises the term ‘dyscalculia’.

In 1993 Geary argued for the existence of three categories of dyscalculia based upon fact retrieval, procedural learning and visual-spatial difficulties. This theory described dyscalculia as a result of ancillary brain processes mishandling mathematical data, rather than difficulties with a core numerical processor. The first two subtypes depended upon the relationship between dyscalculia and working memory, which is difficult to establish due to the external effects of mathematical anxiety and the high co-occurrence of dyslexia (see sections 4.3.1 & 4.6). The relationship between dyscalculia and visual spatial difficulties is still poorly understood, with differing opinions as to whether this is a characteristic of dyscalculia, or evidence of a separate neurodiversity such as dyspraxia (see section 4.3.2).

In the late 1990s there was a realisation amongst many researchers (Butterworth, 1999; Dehaene, 1999) that dyscalculia encompassed a deeper misunderstanding of mathematical concepts than just poor performance on arithmetic tests and that dyscalculic individuals may be able to perform mathematical tasks if they can learn a procedure, but have no true understanding of the meaning behind the tasks. Sharma (1997) was one of the first to acknowledge that arithmetic achievement was not necessarily a suitable measure of mathematical understanding, and claimed that a true indicator of dyscalculia would be:

An inability to conceptualise numbers, number relationships (arithmetical facts) and the outcomes of numerical operations (estimating the answer to numerical problems before actually calculating). (Sharma, 1997)

Tests for dyscalculia therefore began to focus on the ability to conceptualise number and mathematical constructs, alongside questions testing for arithmetic skills.

Since the turn of the century, dyscalculia research has been facilitated by advances in cognitive theory and neuroscience. As researchers become closer to successfully mapping the mathematical processes of the brain, it can be seen how a problem with one or more components of a cognitive model could explain the characteristics observed from dyscalculia (see section 3.5). Butterworth (1999) claimed that a single component of the brain, referred to as the number module, is responsible for mathematical thinking. The number module is inherent and allows newborn humans and animals to compare
number without the need for instruction. This is referred to as numerosity and is the property of describing a number of objects or the size of a single object, or a comparison between two amounts, for example choosing which tree is bearing the most fruit. Butterworth went on to argue that processing difficulties within the number module would cause mathematical misconceptions at a fundamental level. Subsequent layers of mathematical learning would be unsound due to insecure mathematical foundations (see section 3.8.1).

An alternative theory from Dehaene (1999) claimed that the mathematical processes of the brain are distributed amongst separate logical modules that handle differing ways to represent number: symbolic, verbal and analogous. Cases of dyscalculia in this model would vary depending on which module or modules were behaving atypically (see section 3.8).

Since the advent of advanced MRI scanning techniques, neuroscientists have been attempting to map these models on to physical areas of the brain, the process of which is added for background information in appendix M.

3.3 Definitions of dyscalculia

Dyscalculia is multi-facetted and difficult to define in a few words, resulting in a myriad of definitions, none of which are universally agreed upon (Shalev et al., 2000). Researchers have also historically used different terminology to describe dyscalculia, e.g. the American term mathematical learning disorder (MLD), dependent upon the social or medical stance taken (Oliver, 1990). A tabular summary of the most commonly referenced definitions can be found in appendix A. Due to the need for brevity the definitions are unable to capture the characteristics of dyscalculia in any depth. A more detailed discussion on the mathematics-related difficulties associated with dyscalculia is provided in section 3.5.

The original definition from Kosc (1974) (see appendix A) can be considered as belonging to the medical model of disability, as it focussed on deficits in the brain compared to a neurotypical individual. Subsequent definitions, such as DSM-5 (American Psychiatric Association (DSM-5), 2013), have added some social model themes by looking at the problems encountered in life and education, thus facilitating the construction of support strategies (see appendix A). Having developed a largely social model definition for dyslexia (Rose, 2009), the British Dyslexia Association (BDA) have also worked with Chinn to introduce an equivalent for dyscalculia (see appendix A).
The majority of current definitions follow what is termed the ‘discrepancy model’, which follows a general philosophy that an individual is dyscalculic if their ability to perform mathematics is significantly below their general intelligence (Department for Education and Skills (DFES), 2001; Shalev & Gross-Tur, 2001). There are however further factors that need to be taken into consideration. Each definition can be parsed to extract a set of universal criteria that allows for comparison. These criteria can be categorised into two types: inclusion and exclusion.

### 3.3.1 Inclusion criteria

Inclusion criteria determine attributes of the neurodiversity that must be in evidence. The following criteria feature as key characteristics in many definitions.

#### 3.3.1.1 Mathematical ability

This is the critical criterion that defines dyscalculia and describes difficulties performing mathematical tasks. It forms part of every definition. Early definitions used to refer to poor achievement in arithmetic procedural standardised tests, as researchers had primarily focussed on arithmetic operations because the competency development in neurotypical children was well understood (Geary & Hoard, 2002). Early testing for mathematical ability was focussed solely on the ability to perform arithmetic tasks, however current definitions focus more on number conceptualisation as the defining factor, which addresses an understanding of number properties, estimation, and how numbers relate to each other (Sharma, 1997; Von Aster & Shalev, 2007). Research has shown that dyscalculic students are able to learn arithmetical procedures by rote (Temple, 1991; Trott, 2010b), with little understanding of the underlying concepts. A fundamental failure to comprehend the meaning of number, as opposed to a difficulty in performing arithmetic, is more consistent with theoretical explanations for dyscalculia, such as Dehaene’s ‘number sense’ (1999) or Butterworth’s ‘number module’ (1999).

#### 3.3.1.2 Numerosity and quantification skills

More recent research (Butterworth, 2005a) suggests that the key to dyscalculia lies solely in the individual’s ability to estimate numerosity and subitise (accurately assess number cardinality without counting). I believe that a lack of these fundamental skills could be indicative of dyscalculia, but it is unclear whether numerosity and subitising difficulties should be a necessary characteristic of all dyscalculic individuals. The idea that numerosity and subitising issues are key characteristics is contrary to the discrepancy model, and suggests that dyscalculia is less likely to be a spectrum of
Chapter 3 - Dyscalculia

severity, but a rarer neurodiversity that is separate to other mathematical learning difficulties.

3.3.1.3 Age appropriateness

Any tests used in identification must be age appropriate for the individual. This is required to ensure that the correct score for a person’s age is established for a standardised test. This criterion not only refers to age specific testing for children, but also that adults are not given ‘childish’ tests that could also be de-motivating. The DSM-5 definition (see appendix A) also specified that a test should be not only age appropriate, but culturally relevant.

3.3.1.4 Intelligence disparity

The intelligence disparity criterion is the founding principle of the discrepancy model of dyscalculia (and other neurodiversities). It describes when a dyscalculic individual’s ability to perform mathematical tasks is substantially less than would be expected from the person’s intelligence, which can be evaluated by comparing the individual’s mathematical level against their general ability level, as measured by IQ. Mazzocco and Myers (2003) preferred to use peer comparison rather than IQ; they claimed that reliable IQ measurements are not attainable, and specified comparisons of "age-matched and grade-level matched peers within similar educational environments“ (p3) as a means of determining whether children were under performing in mathematics. Maehler and Schuchardt (2011) had similar concerns about the effectiveness of using IQ, as, they claimed, measuring intelligence is known to be problematic (Gardner, 1993). One issue is that IQ is a composite of a range of intelligence measures, which includes mathematical ability. Therefore IQ would be downwardly affected by dyscalculia and not a true reflection of general intelligence. Researchers would have to either gauge this effect, or create a new IQ measure independent of mathematical ability to estimate intelligence disparity more accurately.

The intelligence disparity criterion raises the question of whether someone with a general learning disability (GLD) can have dyscalculia, as their specific mathematical difficulties may not be distinguishable from their overall poor academic performance. Some definitions would claim this is impossible as there has not been a failure to reach academic potential, while others might state that even if this was true, the GLD would make the inherent dyscalculia impossible to identify. The intelligence disparity, or discrepancy, is also used within many dyslexia definitions. For example the British Dyslexia Association (2012) (appendix A) includes the intelligence disparity in its officially recognised definition with the phrase "may not match up to an individual's other
cognitive abilities”. Some researchers however are critical of this approach within a
definition for dyslexia (Stanovich, 1991; Siegel, 1992; Stuebing et al., 2002). If the
criterion of ‘numerosity and quantification skills’ is a valid and thorough indicator of
dyscalculia and can be effectively assessed, then intelligence disparity as a criterion for
dyscalculia would become redundant.

3.3.1.5 Recollection of number facts

This is a test of an individual’s ability to store mathematical facts into long-term
memory, a process which can be inhibited by working memory difficulties. Although
some researchers highlight the inability to remember number facts and execute
calculation procedures as an important feature of dyscalculia (Geary, 1993; Shalev &
Gross-Tur, 2001; Landerl et al., 2004), others point out that some dyscalculic
individuals are still able to perform procedural methods accurately, despite the lack of any
underlying understanding (Temple 1991). Difficulty in remembering number facts is a
major factor in dyslexic learners showing mathematical difficulties. However poor
working memory could signify mathematical anxiety, which is separate to, yet strongly
linked with dyscalculia. Mathematical anxiety is a "feeling of tension, apprehension, or
fear that interferes with math performance“ (Ashcraft & Kirk, 2001, p1) and is discussed
in detail in sections 4.4.1 and 8.4. Students with dyscalculia in supportive environments
that can compensate for mathematical anxiety can find that they can ‘free-up’ working
memory that can be used as a procedural coping strategy (Drew, 2013).

3.3.1.6 Educational and everyday issues

Using definitions that reflect the social model, it is impossible for dyscalculia to exist and
not be evident in an educational setting assuming educational opportunity has been
available. Educational issues are likely to be most noticeable in subjects with a high
mathematical content, but numbers can appear in every subject, e.g. dates in history.
Dyscalculia may also be evident through difficulties encountered in real life situations, as
mathematics is a fundamental part of the real world and how we interact with it. If the
criterion of educational and everyday issues is valid then this could imply that any past
career or life choices may have been influenced by the need to avoid mathematical
situations. Although everyday life and educational issues are part of the widely
recognised DSM-5 definition (American Psychiatric Association (DSM-5), 2013), very few
prevalence research studies consider these as participant selection criteria. Most
dyscalculia studies are child-based, and as a result are unlikely to have explored this
criterion to any great extent in deciding whether the participants are dyscalculic.
3.3.1.7 Persistence

For this criterion to be addressed there must be evidence of dyscalculia over a period of time, rather than from a single snapshot of data (Shalev et al., 2005). By definition (see section 4.1), a neurodiversity must be a life-long effect, and therefore dyscalculia continues into adulthood. Auerback et al. (2008) introduced the concepts of persistent dyscalculia (PD) and non-persistent dyscalculia (NPD). Although the research behind the paper was valuable, determining whether behaviour issues in children are related to dyscalculia, the term non-persistent dyscalculia assumes that dyscalculia can be a childhood effect and dissipate with age. Clearly Auerback and colleagues were seeing some form of non-permanent mathematical difficulty, but because of the persistence criterion this cannot be dyscalculia. The dyscalculic student can be supported, so that appropriate coping strategies diminish some effects, and academic intervention or improved social factors can address the issues, but it is not a medical condition that can be treated or removed and is independent of any remedial intervention strategy (Shalev et al., 2005). As all the prevalence studies I have examined have involved children, some of the behaviour identified could be the result of slower cognitive development rather than a long-term difficulty. The younger the child, the greater the likelihood that the learning difficulty may recede, since at ages below eight to nine, the problem may be temporary and not persist as would a true specific learning difference (Shaywitz et al., 1992).

3.3.2 Exclusion criteria

Exclusion criteria are alternative plausible explanations that could result in characteristics similar to those associated with dyscalculia. To be confident that the characteristics are dyscalculia related, the existence of these alternative causes would need to be investigated. Evidence of these factors would not disqualify an identification of dyscalculia, but makes a sound identification more difficult.

3.3.2.1 Educational opportunity

Failings due to inadequate education could be a cause of mathematical difficulty (Dellatolas et al., 2000). Clearly poor teaching (Peard, 2010), inappropriate schooling or prolonged school absence could cause fundamental misunderstandings with some number concepts, and any administered test should not presume any level of familiarity with educational mathematics notation such as column addition or the long division symbol.
3.3.2.2 Appropriate motivation

Some definitions (Shaley & Gross-Tur, 2001) make it explicit that motivational issues need to be discounted to ensure a true identification of dyscalculia (Sjöberg, 2006), and social factors such as poverty and cultural pressures can also impact on mathematical development (Gross-Tsur et al., 1996; Dellatolas et al., 2000). For example, some cultures may discourage children from reaching their educational potential in preference for an early vocational path such as an apprenticeship (Choy, 2001), and this needs to be understood as a possible reason why a student may not have fully engaged with the educational process, despite the opportunity being available. In some cultures it may be seen to be ‘cool’ not to be good at maths (Sullivan et al., 2006).

3.3.2.3 Absence of unrelated impairments

Brain trauma can result in acalculia, which gives similar mathematical learning difficulties to dyscalculia. Sensory impairments such as visual tracking or hand-eye co-ordination (Ramaa & Gowramma, 2002) can prevent a learner from accessing education as efficiently as peers, and provide an alternative reason for poor mathematical performance. Visual stress (see section 4.5) is another potential explanation for mathematical difficulties (Evans, 2001). These extenuating possibilities need to be considered before a dyscalculia identification can be made (World Health Organisation (ICD-10), 1992; American Psychiatric Association (DSM-5), 2013).

3.3.2.4 Alternative neurodiversities

Other neurodiversities can also influence mathematical learning differences, and need to be discounted to identify dyscalculia (World Health Organisation (ICD-11), in press). The most common are other specific learning differences such as dyslexia and dyspraxia, which can be misinterpreted as dyscalculia. Dyscalculia is often found to co-occur with dyslexia (Gross-Tur et al., 1996), and although there does seem to be a high prevalence of co-occurrence, this can lead to cases where dyscalculia is incorrectly attributed to dyslexia with mathematical difficulties, or vice versa (Kaufmann et al., 2013; Drew & Trott, in press). Extremely rare neurological disorders such as Turner’s syndrome and Fragile X syndrome can also provide an alternative explanation for similar mathematical difficulty characteristics (Shaley et al., 2001).
3.3.2.5 Emotional well-being

Mental well-being or emotional difficulties may impact on dyscalculia studies where individuals demonstrate problems such as “maladjustment, withdrawal, over-anxiety, erratic behaviour and aggressiveness” (Ramaa & Gowramma, 2002, p78). The most common example of this is mathematical anxiety which could result in all these characteristics (see section 4.4). This raises the question of how dyscalculia can be identified in isolation from mathematical anxiety, as any mathematical test, by definition, will include numbers and could create anxiety. Consideration of mathematical anxiety is notably absent from most prevalence studies, so I suggest the results should be considered potentially as a hybrid of dyscalculia and mathematical anxiety, rather than dyscalculia in isolation. Reigosa-Crespo et al. (2012) acknowledged in their large prevalence study that “math anxiety or attention disorders could also be related, but have not been fully explored” (p132).

3.4 Prevalence of dyscalculia

Differing views on pre-requisite criteria for identification of dyscalculia have led to a lack of consensus of diagnostic instruments (Shalev & Von Aster, 2008) and a variety of threshold classifications. This has resulted in a range of prevalence statistics, however an incidence of 3-9% of the general population (Munro, 2003; Desoete et al., 2004; Geary, 2004; Butterworth, 2005a; Reigosa-Crespo et al., 2012) is now widely accepted, which is comparable with figures for dyslexia (Rose, 2009). Some theories contradict this and suggest that true dyscalculia is much rarer at around 1% (American Psychiatric Association (DSM-IV), 1994), claiming that some prevalence figures do not allow for factors such as poor education (Peard, 2010) or poor motivation (Sjöberg, 2006) which are independent of dyscalculia. Reigosa-Crespo et al. (2012) in a recent study produced two prevalence values, one based on Butterworth’s ideas of numerosity and quantification skills (see section 3.3.1.2) being the critical factors of dyscalculia (3%), and another incorporating the discrepancy model, assuming dyscalculia consists of a wider spectrum of mathematical difficulties (9%).

A single formal definition would allow for consistency of individual assessment and greater accuracy of prevalence statistics. Although researchers who have undertaken prevalence studies quote prominent definitions such as DSM-IV (American Psychiatric Association (DSM-IV), 1994), their interpretation and implementation of those definitions varies enormously. Appendix B shows a detailed summary of a number of well-cited dyscalculia prevalence studies.
The most notable factor in the range of prevalence statistics is the range of research instruments employed to gauge mathematical difficulties. Early testing used either normed arithmetic tests (Lewis et al., 1994), qualitative assessment from teachers (Ramaa, 1990) or children who had been previously registered as requiring mathematical assistance (Ostad, 1998). From around the mid-nineties (Gross-Tur et al., 1996) screening and identification tests for dyscalculia began to incorporate a number conceptualisation element, but most instruments were specifically designed by the researchers and therefore unhelpful for comparison between studies. The thresholds employed for identifying participants with mathematical difficulties varied too: between one to two standard deviations below the mean (Desoete et al., 2004; Koumoula et al., 2004), an arbitrary percentile score (Mazzocco & Myers, 2003; Barbaresi et al., 2005) or a student being a number of years behind their classmates in mathematics (Ramaa & Gowramma, 2002).

The variety of criteria chosen has also contributed significantly to the wide range of prevalence statistics. Most studies have included intelligence discrepancy as a pre-requisite for dyscalculia, which has been measured by either a range of minimum standardised scores on an IQ test (Lewis et al., 1994; Mazzocco & Myers, 2003, Von Aster & Shalev, 2007), a chosen percentile on Raven matrices (Ramaa & Gowramma, 2002), or teacher assessment (Desoete et al., 2004). Some earlier studies have used literacy as a means to register standard intelligence, which is not only a controversial measure of IQ, but could discount dyslexic students and provide a prevalence figure that excludes co-occurrence (Gross-Tur et al., 1996; Hein et al., 2000).

Other criteria identified from the various definitions of dyscalculia were only sporadically addressed in the prevalence research. In my literature review of prevalence studies (see appendix B), only Gross-Tur et al. (1996) and Mazzocco and Myers (2003) designed a test to measure persistence by repeating the trials after a period of one and two years respectively, although Desoete et al. (2004) did consider persistence by using teacher assessment. Ramaa and Gowramma (2002) were the only researchers to include any exclusion criteria, designing instruments to remove participants on grounds of medical, emotional, motivational and educational issues.

Social model criteria (see section 3.3.2.1) have been addressed by a few of the prevalence studies. Ostad (1998) and Ramaa and Gowramma (2002) included educational issues by selecting only participants who were receiving support and had already demonstrated mathematical difficulties. Desoete et al.’s (2004) choice of using teacher assessment for selection also indicated an inclination towards a more social model perspective on identifying dyscalculia.
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One general criticism of prevalence studies historically is that they have used children in their samples. Generally very little dyscalculia research has been focussed on adults (Gerber, 2012), and findings within the child population have been extrapolated to be applied to adults. In the most referenced prevalence research I sampled, the oldest age group studied has been fourteen.

3.5 Characteristics of dyscalculia

It has been established that arithmetic performance is not necessarily a good gauge of dyscalculia (Temple, 1991; Sharma, 1997; Trott, 2010b), so how does the abstract concept of poor number conceptualisation manifest itself in the real world? Practitioners in HE learning support have a mandate to recognise, screen, identify and support dyscalculia. Even though the topic is under-researched and in its infancy, there is knowledge about dyscalculia that can be captured from the learning support community. By perusing various neurodiversity support organisations’ resources and HE institution websites, I have collated a list of characteristics that practitioners feel are indicative of dyscalculia. These organisations publish user-friendly online checklists of dyscalculia to raise awareness amongst prospective students who may experiencing dyscalculia-related mathematical difficulties, and hence must be able to describe the characteristics effectively. Many university websites have shared information from the same original source, so the list of websites referenced only denotes where original material has been encountered. The characteristics listed in table 2 have been collated from Trott (2003), Lawson et al. (2003), Beacham and Trott (2005), Trott (2010a), Trott (2010b), British Dyslexia Association (BDA) (2012b) and the BrainHE organisation (Best Resources for Achievement and Intervention re Neurodiversity in Higher Education) (2012).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstractness</td>
<td>Difficulty moving from concrete notions to more abstract ideas.</td>
</tr>
<tr>
<td>Calculations</td>
<td>Dyscalculic individuals fail to use rules and procedures to build on known facts. For example, they may know that 5+3=8, but not realise that, therefore, 3+5=8 or that 5+4=9.</td>
</tr>
<tr>
<td></td>
<td>Difficulties mastering arithmetic facts by the traditional methods of teaching, particularly the methods involving counting.</td>
</tr>
<tr>
<td></td>
<td>Problems aligning numbers in sums (could also be visual stress).</td>
</tr>
<tr>
<td></td>
<td>Problems performing calculations.</td>
</tr>
<tr>
<td></td>
<td>Dyscalculic individuals lack confidence even when producing the right answer.</td>
</tr>
<tr>
<td>Calculators</td>
<td>Problem with paraphasic substitutions (where one number is substituted for another either when writing or using a calculator – the person may verbally say the correct number but push a totally different button. Difficulty using a calculator.</td>
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<td>---</td>
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<tr>
<td>Concentration</td>
<td>Unable to concentrate on mentally intensive tasks.</td>
</tr>
<tr>
<td>Counting</td>
<td>Dyscalculic individuals may be able to count, but have difficulty navigating back and forth, especially in twos and threes. Reliance on fingers for counting as number bonds are not secure. Often told not to, making things worse. Dyscalculic individuals often lose track when counting.</td>
</tr>
<tr>
<td>Decimals</td>
<td>Little appreciation of the concept of place value. Dyscalculic individuals struggle with decimals. Dyscalculic individuals struggle with the concept of non-integers.</td>
</tr>
<tr>
<td>Direction and orientation</td>
<td>Difficulty understanding spatial orientation causing issues following directions. Difficulty reading maps resulting in need to turn map physically to orientate direction. May get confused between left and right and easily disoriented.</td>
</tr>
<tr>
<td>Estimating</td>
<td>Dyscalculic individuals find it difficult to estimate or give approximate answers (this is often taught as the first stage in performing a calculation). Difficulty estimating numbers in real-life (e.g. how much change they will receive).</td>
</tr>
<tr>
<td>Formulae</td>
<td>Can learn methods by rote, but does not understand enough to transfer the knowledge to new problems. Problem understanding what is meant by word-based mathematical questions and picking out the relevant mathematics from word-based content. Problem remembering and applying formulae. Difficulty in understanding mathematical concepts, rules and formulae. Difficulty relating printed questions to mathematical techniques.</td>
</tr>
<tr>
<td>Games and music</td>
<td>Difficulty following directions in sports that demand sequencing or rules. Unable to keep track of scores and players during sports or games such as cards and board games. Difficulty reading musical notation and learning musical concepts.</td>
</tr>
</tbody>
</table>
| **Interpreting results** | Difficulty in interpreting data results.  
Difficulty reading graphs and charts. |
|-------------------------|----------------------------------------------------------------------------------|
| **Measures**            | Problem with concepts such as speed (miles per hour) or temperature.  
Conceptual problem with units of measurement. |
|-------------------------|----------------------------------------------------------------------------------|
| **Memory and recollection** | May have problem recognising faces as they are a form of symbol recognition.  
Poor recollection of names. Poor name/face retrieval.  
May substitute names beginning with same letter. |
|-------------------------|----------------------------------------------------------------------------------|
| **Mental arithmetic**   | Poor mental arithmetic.  
Difficulty visualising mathematics mentally. |
|-------------------------|----------------------------------------------------------------------------------|
| **Money**               | Problem dealing with exchange of money, e.g. handling a bank account, giving and receiving change, and tipping.  
Unable to financially plan or budget.  
Difficulty estimating the cost of the items in a shopping basket, or the amount of change to be received. |
|-------------------------|----------------------------------------------------------------------------------|
| **Number facts**        | Does not remember basic number facts, e.g. number bonds.  
Difficulty learning times tables.  
Difficulty remembering and dialling phone numbers.  
Problem recalling names and dates. |
|-------------------------|----------------------------------------------------------------------------------|
| **Numerosity**          | Difficulty understanding the concept of positive numbers as indicators of order and size.  
Problem sequencing numbers (from small to large, for example).  
Conceptual difficulty with size (which is bigger – 10 or 100?).  
Unable to recognise that an answer is unreasonable.  
Problem mentally estimating the measurement of an object or distance (e.g., whether something is 10 or 20 feet (3 or 6 meters) away). |
|-------------------------|----------------------------------------------------------------------------------|
| **Reading and writing numbers** | General problem with reading and writing numbers (even when just copying).  
The number of zeros can cause a particular problem.  
Difficulty grasping that the words ten, hundred and thousand have the same relationship to each other as the numerals 10, 100 and 1000.  
Difficulty understanding written numbers (in word rather than number format) |
### Characteristics of Dyscalculia

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sequential steps</strong></td>
<td>Problem following sequential directions (including reading numbers out of sequence, substitutions, reversals, omissions and doing operations backwards). Dyscalculic individuals struggle to organise detailed information. Difficulty in activities requiring sequential processing and following steps in a mathematical process.</td>
</tr>
<tr>
<td><strong>Slow processing</strong></td>
<td>Dyscalculic individuals are much slower to work out answers in mathematics.</td>
</tr>
<tr>
<td><strong>Stress and anxiety</strong></td>
<td>Increased stress and fatigue. Experiences anxiety and exasperation.</td>
</tr>
<tr>
<td><strong>Subitising</strong></td>
<td>Inability to recognise the number of items up to six without counting.</td>
</tr>
<tr>
<td><strong>Symbols</strong></td>
<td>Failure to notice mathematical signs and symbols. Difficulty remembering what different symbols mean, e.g. four main operators.</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>Difficulty reading timetables and planning time schedules. Problem telling the time on an analogue clock. Problem remembering appointment times. Difficulty in interpreting a 24 hour clock. Difficulty conceptualising time. Problem keeping track of time, and unable to instinctively judge the length of passing time. May be chronically late or early.</td>
</tr>
</tbody>
</table>

**Table 2 – Characteristics of dyscalculia**

Some of these traits may have been deduced from scientific method, others are anecdotal, but what this list does give is a snapshot of the characteristics that current practitioners believe are indicative of dyscalculia, irrespective of any evidence of their necessity, veracity or commonality. All these traits were used as codes within my analysis, and allowed me to formulate my own views of the importance and relevance of each (see section 7.5.2).

### 3.6 Dyscalculia and time

The theme of time-related difficulties has emerged as a significant topic in this study, although there is little previous research into the relationship between dyscalculia and time. The concept of time can be considered from the perspective of Newtonian mechanics comprised of a non-decimal system of hours, minutes and seconds, also known as astronomical time (Newton, 1726/1972). From a socio-cultural perspective,
time can also be considered as a social construct requiring an understanding of both the mathematical concepts of time and the way in which time is used within particular cultural groups. Sorokin and Merton (1937) claimed that social systems of time developed out of the need for social collaboration and that “the rhythm of collective life” defined the units of social time (p615). They cited as an example a highly specific cultural reference within an indigenous Madagascan society where a unit of fifteen minutes is expressed as ‘the time in which an ear of corn is roasted’. For such a unit to have meaning, an individual would need to have experienced an ear of corn roasting and also have the ability to judge approximately how long the process takes. Therefore the ability to judge the passage of time is an important skill within the socio-cultural concept of time.

White et al. (2010) observed that some English speaking cultures rely heavily on astronomical time to co-ordinate social interactions, and lateness is often considered rude, whereas other cultures, such as those of Latin America and North Africa, deem punctuality less important. Newman (2013) suggests that social time in Anglo cultures has become “an economic commodity, something that can be exchanged for money, wasted, shared, or saved” (p108). Comprehension of both astronomical time and culturally specific references are therefore an expected part of membership of a social group in the UK.

3.7 Definition of mathematics

Dyscalculia is broadly defined as a specific learning difference that affects the understanding of mathematics, however, the term mathematics is not always used consistently within these definitions. Academics and dyscalculic students can have varying interpretations on what constitutes mathematics, and it also unclear whether terms such as arithmetic and numeracy are employed as synonyms or have subtle differences in meaning. For this thesis it is important that I define these terms carefully and appreciate what is meant by them when used by others.

The original definition of dyscalculia by Kosc (1974) referred to an ability to perform mathematics. The Oxford English dictionary defines mathematics as:

> The science of space, number, quantity, and arrangement, whose methods involve logical reasoning and usually the use of symbolic notation, and which includes geometry, arithmetic, algebra, and analysis. (Oxford English Dictionary (OED), 2013)

I have chosen to use the term mathematics, in the context of dyscalculia, as an umbrella term that covers all areas upon which the neurodiversity may impact. This includes
spatial awareness, such as left and right recognition, sequencing of tasks and time perception.

More recent definitions have used the term ‘arithmetic’ rather than mathematics. Arithmetic is generally considered as a subset of mathematics that involves calculations, quantities, comparison, ratios, proportion, fractions and percentages, although it is probably most associated with the four operations of addition, subtraction, multiplication and division. Although definitions for arithmetic vary, there seems to be a general consensus that it consists of mathematical tasks that could be found in everyday life. When definitions of dyscalculia have referred to arithmetic difficulties, the emphasis has been on the ability to perform everyday mathematical tasks, rather than any higher level understanding of number properties, and extraneous topics such as geometry, statistics or algebra. To some extent the restriction of the domain of mathematics to being what is relevant in the real world could be viewed as a social model interpretation of dyscalculia. Numeracy is another term that has a similar meaning to arithmetic, and can be described as:

An individual’s capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual’s life as a constructive, concerned and reflective citizen. (Programme for International Student Assessment (PISA), 2009, p14)

This suggests that numeracy also relates to everyday life situations, but is a transferable skill; the ability to apply arithmetic correctly to the given situation. Numeracy is therefore the correct application of mathematical skills in multiple contexts. Although it is likely that a dyscalculic individual would struggle with numeracy from the perspective of meaning, arithmetic does however incorporate a number of learnable procedures and number facts that could be utilised by a learner with neurotypical memory skills. For example a dyscalculic individual does not require any mathematical ability to know that seven times nine is 63, once that fact has been retained in long term memory, however a lot of memory capacity and functional recall is needed to deal with all facts this way. The rote enactment of procedures is not indicative of an integrated cognitive structure for the relationship between numbers (Maclellan, 2001).

The phrase ‘number conceptualisation’ is more commonly used in definitions of dyscalculia to describe the deeper mathematical understanding required to act strategically to solve newly encountered problems, without external instruction. Sharma (2013) compared number conceptualisation to Dehaene’s (1999) number sense:
Number sense is an emerging construct that refers to a child’s fluidity and flexibility with numbers, the sense of what numbers mean, to look at the world quantitatively and make quantitative and spatial comparisons using mental calculations. (Sharma, 2013)

Therefore more recent definitions of dyscalculia tend to use a wider definition of mathematical difficulty beyond arithmetic (see appendix A). Whilst the term numeracy includes an element of understanding application of arithmetic, the phrase number conceptualisation, or number sense better describes the underlying knowledge required to appreciate the relationship between numerical constructs.

It is imperative I understand the meanings implied when the participants in this study describe their mathematical difficulties. With non-academics in an interview forum the use of terms to describe mathematics may be less succinct and more open to conjecture. For example ‘the basics’ is sometimes used to describe some fundamental level of mathematical understanding, but the term may have alternative meanings for different participants. As the term is not used academically, it has no specific meaning. Some participants may use it to infer the four operations, while others may believe it represents all mathematics learnt at primary school.

The term ‘statistics’ is also problematic. Whilst some accept this is a subset topic of mathematics, others may view it as a separate entity. This led to confusion when a student in my study asked whether a course contained any mathematics; the academic staff considered statistics differently, and inadvertently misled the student by claiming that a course contained no mathematics.

### 3.8 Cognitive theories on dyscalculia

As researchers are yet to agree on the cognitive mechanism of performing mathematics, it follows logically that any theory of dyscalculia must be built upon assumptions of how neurotypical learners process mathematical understanding. The following theories are medical model based and use language more appropriate to that paradigm.

Developmental dyscalculia is, within the medical model, defined as a “dysfunction of developing neural networks specifically for the numerical domain” (Von Aster & Shalev, 2007), but the exact regions of the brain that affect mathematical processing are still not fully understood, although experimental research has established that the intraparietal sulcus (IPS) is involved in the undertaking of mathematical tasks (see appendix M). There are three main cognitive theories as to the cause of dyscalculia. The numerical core deficit model (see section 3.8.1) is explicit in defining a single mental component that is responsible for the neurodiversity, which would suggest that all dyscalculic
individuals would have similar characteristics. The other two models (see sections 3.8.2 and 3.8.3) allow for a variety of mathematical difficulties, where differing mental processes could be responsible, giving rise to subtypes of dyscalculia (Kaufmann et al., 2011).

### 3.8.1 Numerical core deficit model

Butterworth (1999) claimed that there is a single inherent cognitive process called the 'number module' that allows humans and animals to recognise numerosity, i.e. the magnitude of a set of objects. The number module consists of two systems; firstly the parallel individuation (PI) system is used for subitising small amounts, which is the precise recognition of the size of a set of objects without counting. The term subitising was created by Kaufman et al. (1949) and was described as the rapid, accurate, and confident judgment of number performed for small numbers of items. A neurotypical individual can usually accurately subitise up to five items (Butterworth, 1999). The second system is referred to as the approximate number system (ANS), and is used to estimate the numerosity of larger sets of objects, and to compare between numerosities. Butterworth (2005b) claimed that if the number module was not performing neurotypically, then dyscalculia would be the result:

> One of the key debates is whether the child is helped to understand the special numerosity meaning by possessing a specific innate capacity for numerosities, rather than, say, a capacity for dealing with, or being sensitive to, quantities more generally. Crucial evidence comes from the people who appear to have a selective deficit in this capacity which profoundly affects their ability to learn arithmetic. This condition is known as dyscalculia (Butterworth, 2005b).

This model of dyscalculia entails a core cognitive difficulty in judging numerosity, causing individuals to struggle with simple tasks, such as numerical magnitude comparison and counting small numbers of dots (Butterworth & Reigosa-Crespo, 2007). All subsequent difficulties with mathematics are therefore created because this fundamental skill is not secure. This view of dyscalculia corresponds to the criterion of numerosity and quantification skills in the breakdown of dyscalculia definition criteria (see section 3.3.1.2).

### 3.8.2 Numerical domain-specific deficit model

This cognitive model builds upon Dehaene’s (1999) theory of the triple code that claimed mathematical understanding is not achieved through a single process (number module), but by a distributed set of processes that are responsible for handling mathematical
representations in different ways. This set of three inter-connected mathematical processes was referred to by Deheane as 'number sense', and is responsible for verbal number representation, visual Arabic code (representing numbers by digits) and analogous magnitude representation (e.g. number line) (see figure 4).

Case in 1998 defined number sense as an ability to move “seamlessly between the real world of quantities and the mathematical world of numbers and numerical expressions” (p1). Gersten and Chard (1999) claim that ‘number sense’ as a term began to emerge in the later 1990s and was referred to by them as fluidity and flexibility with numbers. They also highlighted that good number sense would facilitate the invention of procedures for conducting numerical operations, representing the same number in multiple ways, determining number patterns and having a sound sense of number magnitude that can recognise gross numerical errors.

In this model, the three modules form an autonomous, interconnected system for processing and calculating numbers, where each process is activated when required by a particular task (Von Aster, 2000), although they are located separately within the physical brain; verbal number representation is associated with the left hemisphere, whereas symbolic number representation is found in the right. These regions are not dedicated to number manipulation, but could be used to perform non-mathematical tasks.
A fundamental question, however, is whether any part of the IPS [intraparietal sulcis] region is truly dedicated to number. Does the IPS region behave like a specialised “number module,” as proposed by Brian Butterworth, where neurons are involved with nothing but arithmetic? Sometimes the brain does indeed dedicate an entire patch of cortex to a very precise and important function, for instance the recognition of faces. However, for number, the answer is more complex (Dehaene, 1999).

An example of where difficulties with the various representations of number could create a flawed mathematical construct is the idea of an incorrectly-formed mental number line. Dehaene (2003) described how the mental number line for some individuals may be logarithmic rather than linear, which allows for the correct sequencing of numbers but causes problems when comparing intervals. Piazza et al. (2010) explained how "logarithmic compression implies that the overlap between numbers increases with magnitude, which in turns decreases their discriminability” (p33). Researchers have shown that the formation of a highly logarithmic mental number line is a strong indicator of dyscalculia (Feigenson et al., 2004; Ashkenazi et al., 2009; Anobile et al., 2012).

Moeller et al. (2012) believed that the ability to represent number with the use of fingers is distinct from the representations defined in Dehaene’s triple code model, and would be controlled by a separate fourth cognitive process. This could explain the link between mathematical difficulties and finger agnosia, the inability to distinguish, name, or recognise the fingers, which is a major characteristic of Gerstmann’s syndrome (Gerstmann, 1940).

Dyscalculia under the numerical domain-specific deficit model could occur as a consequence of a problem with one or more of these processes, or problems in connecting these neural networks (Wilson & Dehaene, 2007). This could result in differing characteristics between dyscalculic individuals depending on which of the triple code cognitive processes were affected.

### 3.8.3 Domain-general deficit model

This cognitive model assumes that dyscalculia is not caused by any fundamental issues related to the understanding of number, but rather by the supporting cognitive areas that are part of a unified process for manipulating number, such as working memory, semantic memory, visual spatial skills, attention span or logical reasoning (Rourke & Conway, 1997; Von Aster, 2000; Geary, 2004) (see figure 5). This theory supposes that the numerical skills of the dyscalculic individual remain intact, but cannot be accessed or performed correctly due to difficulties in these over-arching processes. This proposition
does not contradict other theories on neurotypical mathematical cognition, only the root cause of dyscalculia:

*Although it is widely agreed that possession of something like the concept of numerosity is necessary for normal arithmetical competence, it is by no means agreed how individuals arrive at this concept (Butterworth, 2005b).*

For the domain-general deficit model to be true, any observable external difficulties must not be caused by any underlying mathematical understanding difficulties, nor as a result of a co-occurrence of other factors, such as dyslexia or mathematical anxiety.

Karagiannakis (2014) published an alternative classification of the domain-general deficit model that acknowledges that there is a potential core number deficit, but also stipulates that mathematical difficulty could be located within other mathematical cognitive areas. His model proposes four subtypes: core number, memory, reasoning and visual-spatial. The core number subtype corresponds to the numerical domain-specific deficit model (see section 3.8.2) which includes difficulties with approximation of number, numerosity and representation symbols. Karagiannakis argued that dyscalculia could be caused by difficulties in any of these cognitive components, which would result in highly individualised profiles of mathematical difficulty. There is conflicting evidence with regard to the expanded subtypes of this model, and how they relate to dyscalculia. Memory, reasoning and visual-spatial difficulties are all associated with mathematical difficulty, but are not characteristics of dyscalculia as specified by the existing definitions. Poor memory could be caused by dyslexia (see section 4.3.1) or mathematical anxiety (see section 4.4.2), and individuals with a co-occurrence of dyscalculia and dyslexia are known to have strong reasoning and visual-spatial skills (see section 4.3.1).

Karagiannakis (2014) acknowledged this criticism and claimed that the model brings “*into the picture mathematical domains other than the ones typically considered by the MLD literature*” (p3). The multidimensional nature of this model attempts to bridge the gap between the concepts of dyscalculia and mathematics difficulties (MD), as it does not choose to distinguish between the two. His model is not necessarily attempting to pinpoint the nature of dyscalculia, but to provide a spectrum of MD as a whole that is inclusive of all students who struggle with mathematics.
3.9 Summary

This chapter formed the literature review of dyscalculia and catalogued the existing definitions used for the identification and the prevalence of dyscalculia, and current cognitive and neuroscientific theories to examine the nature of dyscalculia from a medical model perspective. As time was a theme to emerge strongly from my data, I also included a literature review of existing research that connects difficulties with time management with dyscalculia.

For the purpose of this thesis two models of dyscalculia were considered: the discrepancy, and the core-module deficit models. The discrepancy model forms the basis of most current definitions of dyscalculia (see section 3.3.1.4) and is therefore the model that all officially identified dyscalculic students are judged upon. The core-deficit model as proposed by researchers such as Butterworth (see section 3.3.1.2 & 3.8.1) is currently at the forefront of ongoing dyscalculia research and needs to be considered as it proposes a tighter definition of dyscalculia that consists of more fundamental difficulties.
4 Neurodiversity

4.1 Introduction

This chapter looks at other neurodiversities beyond dyscalculia that may lead to a student encountering mathematical difficulties. Although dyscalculia is the specific learning difference most associated with barriers to mathematical understanding, other neurodiversities, most notably dyslexia and dyspraxia, can also cause problems with numbers and mathematics. As Grant (2009) noted, “the neurocognitive profile for all individuals is complex, and when a specific learning difference is present, this complexity can be inadvertently masked by a diagnostic label” (p34). Singer (1998) first used the term neurodiversity as a positive social model description of autism (Grant, 2009). The definition of neurodiversity has since been extended to cover any specific learning difference, with a focus on diversity rather than disability. Grant (2009) acknowledged that a weakness to this concept is that there is an implication that there exists a neurotypical person with which to compare, an assumption which he claimed is “highly questionable” (p34). Grant (2009) offered his own definition of the term ‘neurodiversity’, and although it is lengthy, I felt it is worth including in its entirety as it forms such a strong foundation to my study:

Neurodiversity is present when an exceptional degree of variation between neurocognitive processes results in noticeable and unexpected weaknesses in the performance of some everyday tasks when compared with much higher performances on a subset of measures of verbal and/or visual abilities for a given individual. These everyday tasks, which are dependent on the neurocognitive processing of information, include tasks of learning and remembering, time management, social interaction and attentive span, as well as tasks requiring fine and gross motor movements. It is an umbrella term for it encompasses a range of specific learning differences, including dyslexia, dyspraxia, dyscalculia, ADD/AD(H)D and Asperger’s. One or more specific learning differences may be present simultaneously, and it is possible for some forms of neurodiversity, such as a weakness only in working memory, to lack a well-known diagnostic category, such as dyslexia. Neurocognitive variation may be inherited (i.e. developmental in origin), and/or acquired (e.g. through perinatal or postnatal cerebral trauma). In most instances, neurocognitive variation is lifelong. Neurodiversity is a positive statement of differentiation, for while it explicitly refers to individuals whose everyday ways of thinking and behaving differ in certain key aspects from the majority of people, it rejects the assumption that these differences are dysfunctional and are to be ‘cured’. Instead, there is a societal obligation that others make suitable adjustments and accommodations to enable inherent potential to be fully realised (p35).
The second paragraph highlights how an individual’s difficulties may not be easily attributable to pre-existing collections of characteristics that have been given a label, but the individual would still be considered neurodiverse if an identifiable label did not exist.

The final two sentences affirmed Grant’s belief that the support of neurodiverse individuals should be embedded within the social model. The Developmental Adult Neurodiversity Association (DANDA) explored the overlap of neurodiverse characters in an online published diagram, shown in figure 6 (Developmental Adult Neurodiversity Association (DANDA), 2012). This representation illustrates how definitions of specific learning differences share common characteristics, which taken in isolation could make identification unreliable. Dyscalculia has been shown to overlap with dyslexia and dyspraxia (see section 4.6), as both these neurodiversities contain features that can cause difficulty with manipulation of number or spatial awareness. The diagram does not show an overlap with AD(H)D, which has since been shown by Rubinstein and Henik (2009) to also be associated with mathematical difficulties. One common characteristic strongly associated with mathematical difficulties is poor memory, which affects mental arithmetic and the retrieval of mathematical facts. I have therefore included a literature review of the current understanding of the memory process in the section below.

Figure 6 – DANDA diagram for the make-up of neurodiversity
4.2 Memory

Two aspects of memory were commonly cited in the participants’ narratives in my study: recall of mathematical information, and manipulation of number within working memory. A propensity to “find it difficult to learn number facts 'by heart’” (Department for Education and Skills (DfES), 2001, p5) and to “find that mental arithmetic may overstretch short-term and working memory” (Department for Education and Skills (DfES), 2001, p7) are characteristics of a number of specific learning differences, most notably dyslexia (Trott, 2003). In subsequent chapters I discuss how characteristics of dyscalculia and coping strategies may relate to particular aspects of the memory model.

![Model of memory](image)

*Figure 7 – Model of memory (Baddeley & Hitch, 1974; Thomson, 2001)*

Poor memory is a key characteristic of dyslexia and dyspraxia. This section describes the current understanding of how memory is distributed and organised within the brain. Memory consists of three components which are responsible for the storage and transference of different types of sensory data (Thomson, 2001), as shown in figure 7.
Chapter 4 - Neurodiversity

These are the sensory-register (see section 4.2.1), working memory (see section 4.2.2) and long term memory.

4.2.1 Sensory register

The ‘sensory register’ (see left box in figure 7) is a large repository for transient visual, auditory and tactile (haptic) data that is collected directly from the sensory organ. This data is lost within one to four seconds of decay unless encoded into working memory by attentive consideration (Radvansky, 2010).

‘Working memory’ (see central box in 7) is where manipulation of transitory information takes place, as described by Numminen et al. (2002) as “the cognitive system responsible for temporary storage and manipulation of information during cognitive activities” (p105). It is the component of memory most commonly associated with neurodiversity (Grant, 2009) and is discussed more fully below.

‘Long term’ memory (see right box in figure 7) has the largest storage capacity of the three memory components, and archives episodic, semantic and procedural information. Episodic data covers historical events, which have been time-stamped to provide a retrievable story. Semantic data includes general knowledge and the internal dictionary (lexicon), and how these can be used to provide meaning to the outside world. Procedural information allows for the memorising of action sequences involved in everyday tasks as the steps are consistent, for example driving a car. This allows for regular repetition, which is a key skill used by dyscalculic learners to compensate for difficulties with number conceptualisation (Trott, 2009).

4.2.2 Working memory

‘Working memory’ is the "desktop of the brain" (Thomson, 2001, p113). It keeps track of where individuals place their attention and handles information on a moment to moment basis. The working memory model (see figure 8) created by Baddeley and Hitch (1974) describes the temporary storage and manipulation of information during thinking and reasoning tasks. This model considers the everyday human use of temporary data, where data is required for a short time to make a decision or progress an action, but is then no longer required, e.g. mental arithmetic. Prior to this, the phrase short term memory was used to represent a single conceptual system responsible for temporary storage. Baddeley and Hitch (1974) reconceptualised this to become a complex set of interrelated subsystems which were labelled working memory. The phrases short term memory and working memory are still sometimes used interchangeably in the literature (Baddeley, 2012).
Chapter 4 - Neurodiversity

Working memory acts as the intermediary between sensory input and long term storage. Sensory information destined for long term memory must pass through the working memory system to be encoded. The storage capacity is limited, and data must be rehearsed or be lost. Memory rehearsal is the act of repeating data to facilitate the retention of memories, and takes the form of either elaborate rehearsal or maintenance rehearsal (repetition with or without an associated meaning). Many of the participants in my study used the learning of mathematical facts as compensation for a lack of mathematical understanding, and those that had employed dedicated memory rehearsal techniques demonstrated greater success. Working memory is also used as the buffer to retrieve and formulate long term memory data as a response to external stimuli.

![Working Memory Model](image)

*Figure 8 – Working memory model (Baddeley & Hitch, 1974; Thomson, 2001)*

The working memory model includes a controlling component, entitled the central executive (see section 4.2.2.1), and two subsidiary slave components that handle visual
and auditory data, known respectively as the visuo-spatial sketchpad (see section 4.2.2.2) and the phonological loop (see section 4.2.2.4). In 2000, Baddeley added the episodic buffer to his model to handle abstract representations of past events. This updated model is shown in figure 8. The term ‘short-term’ memory is sometimes used to refer to the storage component of working memory, which would consist of the visuo-spatial sketchpad and the phonological loop under the Baddeley and Hitch model. The term is not however synonymous with working memory as it does not include the structures and processes for storing data that are associated with working memory.

4.2.2.1 Central executive

The central executive acts like a computer processor and directs information between the subsystems of the working memory. It has overall control of memory tasks by “focusing, dividing and switching attention” (Henry, 2011, p21). Hitch (1978) described how impairment of the central executive could cause poor attention, as characterised particularly by AD(H)D (American Psychiatric Association (DSM-5), 2013), leading to disruption to the successful completion of mathematical procedures. Geary (2004) discussed how neurodiverse learners often have “difficulties in monitoring and coordinating the sequence of problem-solving steps, which in turn suggest that functions of the central executive are compromised” (p9).

4.2.2.2 Visuo-spatial sketchpad

The visuo-spatial sketchpad is another sub component that can only hold information for a few seconds, and is distinct from the phonological loop (Baddeley, 1987). Logie (1994), who wrote a number of papers on the visuo-spatial sketchpad and is a co-author of Baddeley, described its use as storage for visual and spatial data within reasoning and memory tasks. Visual data describes the physical appearance of an object, e.g. its shape and colour, whilst the spatial information describes its physical location in three dimensions. The visuo-spatial sketchpad is also involved with the storage of kinaesthetic information (Quinn, 1994) and therefore impairments of this component have been linked with developmental dyspraxia (Alloway & Gathercole, 2006). Mathematical activities require the visuo-spatial sketchpad for the performance of mental arithmetic and virtual shape manipulation.

4.2.2.3 Episodic buffer

Baddeley (2000) adapted the working memory model to include the episodic buffer, which “serves as a modelling space that is separate from long term memory” (p421). The episodic buffer explains how working memory interacts with long term memory and
integrates “information from all the other systems into a unified experience” (Henry, 2001, p4).

Hitch’s exploratory work (1978) on the possible link between working memory and mathematics achievement was formalised by Geary and Widaman (1992) when they demonstrated a strong correlation between working memory and arithmetic problem solving. As neurotypical learners become more adept at solving mathematical problems, they become more reliant on fact recall, e.g. number bonds to improve the efficiency of their procedural strategies (Geary, 2004). Geary (2004) claimed that the retrieval of basic facts reduces the working memory demands and makes the “solving of more complex mathematical problems in which the simple problems are embedded (e.g. work problems) less error prone” (p7). Geary went on to show that dyslexic learners struggle to evolve problem solving strategies from purely procedural techniques, to ones that integrate arithmetic fact retrieval, suggesting difficulties with the storage and access of number-based facts to and from long-term memory (a process which involves working memory). This in turn puts greater load on working memory to perform procedural tasks. A study by Geary et al. (2007) showed that neurodiverse learners with mathematical difficulties had a range of problems across different aspects of working memory, so it seems unlikely that any possible link between dyscalculia and working memory could be attributed to a particular subcomponent.

4.2.2.4 Phonological loop

The phonological loop is a storage area for speech and sounds and is primarily used during reading and the use of language. It is the memory subsystem utilised when sequential data is being held, such as during the digit span task used in assessments (the memorisation of a sequence of digits) or the reversal of digits. The first of two subcomponents, the phonological store, holds auditory memory as a ‘memory trace’ over a period of only a few seconds. The second subcomponent, the articulatory control system, allows data to be held for longer by using vocal rehearsal, a process of verbally repeating data to avoid trace decay (the forgetting of information). Baddeley (2007) used the analogy of a tape recorder on a two second loop. The rehearsal mechanism in adults is usually an internal verbal recitation, described as subvocalisation or the ‘inner voice’ (Baddeley, 1987; Smith et al., 1995).

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4.3 Neurodiversities associated with mathematical difficulties

The following neurodiversities are known to have mathematical difficulties as part of their set of characteristics.

4.3.1 Dyslexia

Developmental dyslexia is the most common neurodiversity (Pollak, 2009), with studies showing considerable variance in prevalence, ranging from 5-17% (Shaywitz, 1998), although a figure of 5% is generally accepted (American Psychiatric Association (DSM-5), 2013). Historically definitions were similar to dyscalculia (see section 3.3) in that they followed a deficit model (Singleton, 1999; Riddick, 2001), but in 2007 the British Dyslexia Association (BDA) created a definition that in part focussed on the neurodiversity from a social model perspective:

Dyslexia is a specific learning difficulty that mainly affects the development of literacy and language related skills. It is likely to be present at birth and to be life-long in its effects. It is characterised by difficulties with phonological processing, rapid naming, working memory, processing speed, and the automatic development of skills that may not match up to an individual's other cognitive abilities. It tends to be resistant to conventional teaching methods, but its effect can be mitigated by appropriately specific intervention, including the application of information technology and supportive counselling (British Dyslexia Association (BDA), 2007).

In medical model terms (see section 2.3.2), dyslexia is “a neurodevelopmental disorder that is characterised by slow and inaccurate word recognition” (Peterson & Pennington,
2012, p1997), which was postulated to be caused by a genetically based difference in the neurological area of the brain that governs phonological processing (Snowling, 2000), and corroborated by De Smedt and Boets in a controlled study (2010). Moll et al. (2013) found that some of the cognitive factors associated with dyslexia, such as phonological awareness, were hereditary (referred to as ‘endophenotypes’), whereas other related cognitive weaknesses, such as impairments in word recall, were not associated with familial risk.

A social model based definition describes a distinct balance of skills (Miles et al., 1995) and highlight how dyslexics often excel at creative tasks and have higher powers of reasoning. The BDA definition above emphasises that targeted support strategies can allow dyslexic students to overcome their learning difficulties and reach their academic potential. West (1997) observed how dyslexics can struggle with simple computation, and yet create mathematical thoughts and ideas that ‘border on genius’. Many notable high achievers, such as Faraday, Da Vinci, Einstein and Shakespeare, were believed to have been dyslexic (West, 1997). A more recent example is dyslexic molecular biologist Carol Greider winning the Nöbel Prize for Chemistry in 2009.

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<td>Holistic viewpoint (can see the big picture)</td>
</tr>
<tr>
<td></td>
<td>Good at recognising patterns, connections, and similarities</td>
</tr>
<tr>
<td></td>
<td>Comfortable with complexity</td>
</tr>
<tr>
<td></td>
<td>Visual, spatial and lateral thinking</td>
</tr>
<tr>
<td>Creativity</td>
<td>Thinking in pictures instead of words</td>
</tr>
<tr>
<td></td>
<td>Artistic ability</td>
</tr>
<tr>
<td></td>
<td>Musical ability</td>
</tr>
<tr>
<td>Traits</td>
<td>Highly curious</td>
</tr>
<tr>
<td></td>
<td>Persistent</td>
</tr>
</tbody>
</table>

**Table 3 – Characteristics of dyslexia**

Despite the difficulty in creating a single definition, there is a general consensus on the typical characteristics of dyslexia (Singleton, 1999; Henderson, 2012; Thomson, 2001; McLoughlin et al., 1994). These are shown in table 3.

One prominent characteristic observed by dyslexia researchers is poor working memory, in the form of reduced verbal span (McLoughlin et al., 1994). Research has shown that dyslexia impairs the storage capacity of the phonological loop (Miles, 1983; Snowling, 2000; Smith-Spark et al., 2003) but it is unclear whether the impairment extends to other parts of working memory.

The characteristics of dyslexia can lead to difficulties with mathematics. Perkin and Croft (2007) showed that dyslexic-related issues could impact negatively on a higher education student’s success in mathematics. As mathematical difficulties can be related to more than one neurodiversity, mathematical difficulties due to dyslexia are sometimes misidentified as dyscalculia (Malmer, 2000). Henderson (2012) observed that in her own experience:

*A few dyslexics can be placed in the dyscalculic category, indicating they have got extreme difficulties with the subject. As for the remainder, there is no clear statistical evidence available to show exactly the nature of their problems, but, as with most*
students, their difficulties lie on a continuum ranging from mild to chronic, all varying in the way they are affected by their inability to achieve success in mathematics (p2).

The difficulties described here are not necessarily fundamental conceptual issues faced by dyscalculic students, but problems with access to questions, or a propensity towards ‘careless mistakes’. Chinn and Ashcroft (1998) observed that:

Many dyslexics have difficulty in at least some aspects of mathematics, but this is not necessarily in all aspects of mathematics. Indeed, some dyslexics are gifted problem solvers despite persisting difficulties in, for example, rote learning of facts (p14).

Historically researchers have concentrated on dyslexia related mathematics difficulties in the domain of young children (Simmonds & Singleton, 2009), and teacher-based accounts have provided evidence of which mathematical tasks dyslexics find difficult, and what support strategies have been beneficial (Miles & Miles, 1992; Chinn & Ashcroft, 1998; Henderson & Miles, 2001). There has been little investigation into the issues encountered by further and higher education students, and Yeo (2002) observed “there is a disappointingly limited body of research and a relatively limited range of literature exploring themes related to dyslexia and maths learning” (p4). Searle and Sivalingam (2004) stated that the “possibility of a dyslexic pupil experiencing serious difficulties with tertiary mathematics is real” (p3).

Trott (2003) categorised these difficulties into three barriers: reading, writing and memory. Reading difficulties can prevent access to mathematical questions; if the student cannot interpret the given instructions correctly, they could fail to produce a correct answer even if they had a robust conceptual understanding of the topic. This is particularly problematic in mathematics, which has its own unique symbolism and language that can create confusion. Dyslexic students therefore need more time before they can associate a symbol with its mathematical meaning (Miles et al., 1995), for example an integral symbol (Trott, 2003). The introduction of new symbols in higher level mathematics can be discouraging for dyslexics and is an area where one to one support can be beneficial.

Henderson (2012) noted that graphs and tables can cause problems because dyslexic students find labels difficult to interpret due to varying font size and the graph or table being located apart from the accompanying text. Figures positioned randomly within text can also cause confusion due to the need to scan backwards and forwards to follow an explanation.

Writing difficulties can take the form of disorganised layout of work, such as creating tabular data or setting out steps in a procedure. Symbols and digits can become
transposed or flipped leading to errors in calculation. Trott (2003) described how dyslexic students can make transcription errors when copying from one medium to another, and can often lose their place, for example writing sixes as nines or addition signs as multiplication.

Memory issues can be present in mental arithmetic, both with mental manipulation of numbers, and the retrieval of arithmetic facts such as times tables or number bonds (Ramus et al, 2003; Snowling 2000). Dehaene (1992) postulated that numerals are held in the phonological loop component of memory therefore reduced working memory capacity inhibits the retrieval of arithmetic facts. Miles (1983) showed that dyslexic children have a particular difficulty with multiplication tables and Landerl et al. (2004) demonstrated that dyslexic children are slower to perform single digit number bond additions and subtraction than their dyscalculic or neurotypical counterparts. Göbel and Snowling (2010) asserted that the above studies were also applicable to dyslexic adults.

As working memory acts as a conduit process in the storage and retrieval of long-term memories, dyslexic students find it difficult to memorise procedural processes and the meaning of mathematical symbols, which could explain why dyslexic students are better at learning mathematics through conceptual understanding. Traditional memorisation techniques focus on verbal repetition, which utilises the phonological loop where dyslexic learners are weakest. Yeo (2002) observed that “over and over again it is commented that dyslexic children fail to learn facts easily in the form of pure verbal associations” (p12). Trott (2003) described various memory aids that may be useful for holding information in long term memory, including large wall posters and index cards to memorise formulae and theorems. She described the key to success as the use of non-verbal senses to utilise storage capacity that does not reside in the phonological loop.

McLoughlin et al. (1994) observed that multi-sensory learning “maximises the chances of establishing new learning by using all available routes to the brain” (p16).

Due to their reduced working memory storage capacity, dyslexics find it difficult to hold several pieces of information at the same time, as part of a step-by-step process. This can be demonstrated in a digit span test, where individuals are asked to recall a sequence of numbers, or repeat a sequence backwards. This reduced capacity inhibits the ability to perform mental calculations, and Trott (2003) observed that:

In multi-step problems, students frequently lose their way or omit sections and fail to hold all the relevant aspects of a problem in mind and combine them to achieve a final solution. They may have problems in sequencing complex instructions, and past/future events (p17).
Trott (2003) discussed how flow or tree diagrams can help to clarify procedures, and described a specific case of breaking down partial differentials into small steps, that are then represented visually, a technique sometimes referred to as ‘keeping in the mind’s eye’ (Chivers, 2001).

One recommendation that covers all of these barriers is dedicated one-to-one support (Perkin & Croft, 2007; Trott, 2011a); this can help the dyslexic student by offering different strategies to overcome many of the above hurdles, and help the student to discover what coping strategies work best for them.

### 4.3.2 Dyspraxia (DCD)

Developmental dyspraxia, or developmental coordination disorder (DCD), is a specific learning difference that impairs the organisation of movement. Historically, various terms have been used to describe characteristics of ‘clumsiness’ that were not consistent with any known neurological impairment (Sharon Drew, 2009). Prevalence figures vary due to the fluid nature of definition criteria, but an extensive 2009 child-based study resulted in a suggested prevalence of 1.8% (Lingam et al, 2009), which was in keeping with estimates between 1.4% and 6% from previous studies (Van Dellen & Geuze, 1988; Wright & Sugden, 1996; Drew, 2009). In contrast, some published figures are as high as 22% using less strict classifications (Drew, 2009). Dyspraxia can affect an individual’s perception, language skills and thought processes (Grant, 2009), which can impair day-to-day functioning and the ability to learn. Some of these issues have a particular impact on learning mathematics or the undertaking of mathematical tasks.

Gross and fine motor-control difficulties give rise to perceptual and spatial weakness including visuo-spatial difficulties which are the key underlying feature of dyspraxia according to many researchers (Yeo, 2002; Portwood, 2000). The inability to visualise tasks underpins “the tendency for dyspraxic children to display inflexible and ‘bottom-up’ inchworm maths processing characteristics” (Yeo, 2002), in contrast to the perceived dyslexic learning style (see sections 2.3.4 & 4.3.1). ‘Inchworm’ here refers to Chinn and Ashcroft’s (1998) classification of mathematical learning; inchworm learners use a methodical step-wise approach to solving problems in contrast to a ‘grasshopper’ learners who use a holistic approach, estimation or lateral thinking to recognise correct solutions.

Fine motor control difficulties can make drawing shapes, graphs and tables difficult and inhibit work with mathematics manipulatives or tools such as a ruler, pair of compasses or protractor (Hull Learning Services, 2004). Yeo (2002) noted that spatial perception
difficulties can inhibit subitising and keeping the ability to track of counting, subitising being the quick, accurate numerical judgments of a small set of items.

Dyspraxia can also “impact on the students’ spatial awareness and alignment of digits” (Drew & Trott, in press), with hand-eye coordination difficulties and left/right confusion being other possible characteristics (Cermak & Larkin, 2002).

Some of the characteristics of dyspraxia are common to other neurodiversities, as represented by the overlap of regions in the DANDA diagram in figure 6. In common with dyslexics, dyspraxic learners often have significant working memory issues, which directly affect verbal and spatial representations of number (Geary & Hoard, 2002), and can cause the reversal of digits or the misplacement of mathematical symbols (Yeo, 2002). Slow processing speed and sequencing difficulties are other shared characteristics of the two neurodiversities that affect mathematical performance. Attention span difficulties, in common with AD(H)D, are also a feature of dyspraxia, and can result in a dyspraxic student being easily distracted within a traditional learning environment.

Dyspraxic learners exhibit typical strengths associated with the left-hemisphere of the brain; many have good verbal mathematics skills and prefer to represent mathematical concepts in verbal language form, similar to dyslexic learners (Yeo, 2002). A dyspraxic student is unlikely to fail in tertiary education due to lack of ability (Drew, 2009); it is more likely due to disorganisation in managing learning or a lack of understanding of the set tasks, and a “lack of awareness and inclusive practice” from institutions and academic staff (Drew, 2009, p103).

### 4.4 Mental health

The mental health, or emotional well-being, of HE students is not a learning difference, but is still a major concern for HEI learning disability departments as it can have a profound affect on the students’ academic and everyday success. Becoming an undergraduate can create many stresses, including the transition from secondary to tertiary education and from home to a new more independent environment, and the financial pressures that accompany that. As more students from a variety of backgrounds enter HE, it is unsurprising that the number of students presenting with mental health difficulties has increased (Royal College of Psychiatrists, 2003).

The emotional well-being of HE students can be affected by emotional difficulties such as depression, anxiety or obsessions. The difficulties encountered by a student with a neurodiversity could create or exacerbate these feelings. Mathematical anxiety is
strongly associated with dyscalculia, and two of my participants showed characteristics of severe generalised anxiety.

This section explores the research that exists around mathematics and statistical anxiety, with specific attention to the effect of anxiety upon working memory.

### 4.4.1 Mathematical anxiety

Mathematical anxiety (MA) is a stress-related response experienced by some individuals when faced with a mathematical task (Sheffield & Hunt, 2007). It is "among a spectrum of anxiety conditions referred to as performance-based anxiety disorders" (Hopko et al., 2003, p649), and is believed to influence the early development of mathematical skills, but its precise origins are unknown (Rubinsten & Tannock, 2010). The prevalence of MA is thought to be in the region of 20% (Jones, 2000).

Sheffield (2006) categorised the characteristics of MA into these response types: psychological, physical and biological. He gave examples of psychological effects as embarrassment, worry and feelings of helplessness. Buxton (1981) gave examples of psychological effects of MA as panic, dislike, bewilderment, fear, fright, terror, stupidity, frustration, and a fear of looking stupid. Richardson & Suinn (1972) had described MA in psychological terms, as a "feeling of tension, apprehension or fear" (p551), whilst Ashcraft and Faust (1994) had observed a sense of "dread that interferes with the ordinary manipulation of number and the solving of mathematical problems" (p98).

Tobias (1978) claimed that these psychological effects were a mistrust of an individual's arithmetic abilities, when required to use those skills in a public setting. Klinger (2010) highlighted confusion as a major psychological characteristic, along with lack of confidence, low self-esteem and self-deprecation.

Physical responses could include panic, dizziness, clammy hands, an upset stomach, raised heart rate and shortness of breath (Sheffield & Hunt, 2007).

Biological effects are more difficult to quantify as they are not externally observable, although of particular interest is the inhibition of working memory (Butterworth et al., 1996). When individuals become mathematics anxious, this concern affects working memory, restricting the flow and control of information required to perform the mathematical task (Beilock, 2011). Ashcraft & Kirk (2001) described this characteristic as MA disrupting "the ongoing, task-relevant activities of working memory, slowing down performance and degrading its accuracy" (p236). The link between working memory and MA is particularly relevant to this study and is discussed in more detail in section 4.4.2.
Sheffield’s classification of responses to MA does not include behavioural responses. These may be external reactions such as avoidance strategies, defacing a maths book or running out of a classroom. These behaviours are a manifestation of the psychological traits, such as low self-esteem leading to low expectations, and a lack of persistence or desire to create coping strategies (Klinger, 2010). These characteristics lead to “self-defeating behaviours that undermine the learning situation unless the teacher/practitioner intervenes successfully” (Klinger, 2010, p155).

Whether MA leads to poor performance, or vice versa, is a subject for debate (Hopko et al., 2003). It is not a neurodiversity in itself, but it does share the life-long persistence characteristic that is inherent of a specific learning difference (Rubinsten & Tannock, 2010). Early years experiences of mathematics do appear to be critical however, as this formative period of children’s mathematical learning can be affected by teachers who may themselves be uncomfortable with mathematics and hide their innumeracy (Klinger, 2009). Mathematically anxious individuals take longer to complete arithmetic tasks and are more prone to non-conceptual errors (Hembree, 1990; Ashcraft & Faust, 1994). Chinn and Ashcroft (2006) noted that modern curricula can reinforce a culture of performing mathematics tasks quickly, exacerbating the negative predisposition of a student with MA.

Mathematical anxiety is assessed using questionnaires which originate from the mathematical anxiety rating scale (MARS) devised by Richardson and Suinn (1972). Mathematics anxious individuals are asked how they would respond in a range of scenarios that require an engagement with mathematical tasks (Sheffield & Hunt, 2007). Ashcraft et al. (1998) introduced a new assessment schedule which demonstrated that MA was correlated to mathematical difficulty, with simpler integer questions not inducing the same anxiety effects. However MA is not exclusively related to mathematical courses or tests. An individual could experience MA when encountering numeracy in everyday life, or even due to the prospect of performing mathematics in the future (Ramirez et al., 2013). Ashcraft and Kirk (2001) observed that:

> It is not necessary to use conventional arithmetic and math problems to trigger the math-anxiety reaction. Instead, it is apparently enough that the task requires a counting-like process (p235).

Although I assumed that mathematical anxiety would be a factor for dyscalculic students in my study, very little research has explored whether a connection exists. In 2010, Rubinsten and Tannock claimed to provide the first “direct evidence linking math anxiety with deficiencies in basic numerical abilities (e.g., retrieval of arithmetic facts)” (p8). They theorised that numerous single-answer addition and multiplication questions
combined with a culture of solving problems quickly, would lead a young dyscalculic pupil towards a negative disposition towards mathematics and a sense of helplessness.

Adults as well as children may experience a high level of anxiety specifically when encountering mathematics, in contrast to reading or spelling. Socially it appears to be acceptable to declare difficulty with mathematics, which allows for avoidance strategies to lower the anxiety (Chinn, 2007). Research has shown that MA is a significant factor in the higher education or career choices of mathematics-averse students (Chipman et al., 1992; Ashcraft, 2002). Sheffield and Hunt (2007) observed that otherwise capable learners with MA avoid mathematics-heavy academic courses, which in turn leads to fewer science, technology and engineering graduates (Hembree, 1990) (see section 8.3).

Preis and Biggs (2001) described a mathematical anxiety life cycle pictorially (see figure 9). This cycle is difficult to break as a ‘catch 22’ occurs when MA leads to poor achievement, which then leads to more anxiety, and becomes a circular trap. The key to escaping this cycle is the use of anxiety reduction techniques rather than mathematical interventions (Hembree, 1990; Arem, 2002). Maloney and Beilock (2012) observed that:

*If exposure to negative math attitudes increases the likelihood of developing math anxiety, which in turn adversely impacts math learning and performance, then regulation of the negativity associated with math situations may increase math success, even for those individuals who are chronically math anxious (p405).*

*Figure 9 – Mathematical anxiety cycle*
Hembree (1990) observed that mathematics anxious learners could improve mathematical performance by the use of strategies aimed at reducing anxiety. As these interventions were independent of mathematical instruction, the ability to perform the tasks must have been latent within the student, albeit repressed by the anxiety. Help in overcoming the mathematical anxiety would therefore be required to permit a true accurate assessment of the student’s abilities. This would be described as creating a positive cycle of confidence (see figure 10) which is a positive transposition to the negative cycle of figure 9. Potential ways of helping a dyscalculic student tackle MA are discussed in section 8.4.5.

Figure 10 – Mathematics confidence cycle

### 4.4.2 Mathematical anxiety and working memory

In 1992 Eysenck and Calvo proposed the *processing efficiency theory*, a model of performance in cognitive tasks related to general anxiety. This predicted that general anxiety could cause a reduction in the "storage and processing capacity of the working memory system available for a concurrent task" (Eysenck & Calvo, 1992, p409). Ashcraft et al. (1998) added that cognitive abilities used for mathematical tasks, such as working memory, could also be adversely affected by anxiety. In a study with undergraduate students, Ashcraft and Kirk (2001) developed this theory by focussing specifically on mathematical anxiety. They discovered a negative correlation between mathematical
anxiety and working memory, implying that working memory could be inhibited by the presence of mathematical anxiety. If an individual experiences reduced working memory capacity, mathematics performance will in turn be affected and decrease (Gathercole & Pickering, 2000; Gathercole et al., 2004; Seyler et al., 2003). Therefore "the intrusive thoughts and worry characteristics of high anxiety are thought to compete with the ongoing cognitive task for the limited processing resources of working memory. The result of such competition is either a slowing of performance or a decline in accuracy" (Ashcraft & Kirk, 2001, p225).

Reduced working memory storage affects a learner’s capacity to process mental tasks or retrieve long term memory data (Eysenck & Clavo, 1992), and mathematics performance is often compromised. Ashcraft and Kirk (2001) hypothesised that MA affects the central executive component of working memory (see section 4.2.2.1).

This has the effect of inhibiting the central executive role in retrieving arithmetic facts (Geary & Widaman, 1992), but it is also known that the visuo-spatial sketchpad component of working memory (Baddeley & Hitch, 1974) is also strongly associated with mathematical tasks (Holmes et al., 2008).

When MA occurs, the effect is to preoccupy working memory, which is a cognitive construct that allows multitasking and the ability to hold information in temporary storage whilst completing other tasks (Alloway, 2006). It is important for storing information about the task, keeping track of progress towards a solution, and representing the task visually (Sheffield & Hunt, 2007). Chinn (2009b) referred to the incidents that cause MA as ‘mental block anxiety’ which:

Refers to triggers, such as symbols or concepts encountered during learning, which create barriers for the learner, for example, the introduction of letters for numbers in algebra or the procedure for long division (p62).

The existence of a mental block associated with MA is an important finding of my research and is discussed in section 8.4.4.

4.4.3 Statistical anxiety

Some researchers have suggested that in addition to mathematical anxiety (MA), there is a separate but related anxiety construct entitled ‘statistical anxiety’ (SA) (Benson
1989; Ziedner, 1991, Onwuegbuzie et al., 1996), however there is a lack of empirical evidence to support this theory (Baloglu, 1999). Ziedner (1990) defined the characteristics of SA as:

> Extensive worry, intrusive thoughts, mental disorganisation, tension, and physiological arousal ... when exposed to statistics content, problems, instructional situations, or evaluative contexts, and is commonly claimed to debilitate performance in a wide variety of academic situations by interfering with the manipulation of statistics data and solution of statistics problems. (p319)

Discomfort with statistics is not just the domain of dyscalculic students. Onwuegbuzie and Wilson (2003) highlighted the increasing number of undergraduate degree courses incorporating statistics-based modules and the need for fluency in statistical techniques. They observed that many students find this a negative experience, particularly when their previous studies at A-level were of subjects unrelated to mathematics. Onwuegbuze et al. (2000) stated that over 75% of undergraduates studying social sciences experienced SA due to compulsory statistical modules, which affected their wider learning.

SA has been found to be not just related to mathematical difficulties, but also dependent upon learners’ perceptions about statistics and any negative previous educational experiences. The factors that lead to SA have been found to be poor mathematics preparation, late academic introduction to quantitative methods, poor disposition to numeracy and poor visual understanding of statistical concepts (Forte, 1995).

For the purposes of this study I do not distinguish between MA and SA, and refer to a general mathematical anxiety that encompasses both types.

### 4.4.4 Escape avoidance

‘Escape avoidance’ is a coping strategy characterised by the effort to protect oneself from the source of psychological damage (Pearlin & Schooler, 1978). Bandura (1993) linked avoidance with self-efficacy and found that “people base their actions in threatening situations on their coping efficacy rather than on anxiety arousal” (p133). Severe cases of mathematical anxiety can lead to a debilitating state of mind which results in the individual feeling compelled to follow an escape avoidance strategy to remove the cause of the anxiety. Escape avoidance can be anticipatory or reactive (Barlow, 2002). A student opting for courses that do not contain mathematics may use escape avoidance in a predictive manner, whereas a student leaving a classroom when asked to perform a mathematical task could be reacting to an unforeseen situation.
4.5 Visual stress

Difficulties focusing on written text are highly correlated to specific learning differences (SpLDs), notably dyslexia. The term visual stress is used to describe these issues, although there may be several different anatomical causes. Evans (2001) described characteristics of visual stress as intolerance to bright light, difficulty keeping a constant image, blurring or moving letters when reading and poor depth perception. This can lead to poor concentration and an inability to read for long periods due to eye strain or headaches.

One common cause of visual stress is Meares-Irlen’s syndrome (otherwise known as scotopic sensitivity syndrome or visual disturbance), which is medically-defined as a hypersensitivity to specific wavelengths of light, caused either by certain photoreceptors in the eye or an impairment of the magnocellular visual system in the brain (Lovegrove, 1991). The magnocellular, or ‘M system’, is responsible for viewing objects that are moving rapidly through the field of vision, in contrast to the parvocellular, or P system, which is a slower process that focuses on the fine detail of objects of interest (Evans, 2001). An M system impairment may result in textual blur due to difficulty focussing on the retina image, leading to visual stress whilst reading (Singleton & Trotter, 2005). However the magnocellular impairment theory has not found universal approval as it fails to explain the high co-occurrence of visual stress with dyslexia (Stein et al. 2000).

Another form of visual stress is ocular instability (or oscillopsia), which is due to abnormal eye movements or impaired vestibule-ocular reflexes (Tilikete & Vighetto, 2011).

Visual stress is strongly associated with neurodiversity, but the reasons for the link remain uncertain (Singleton & Trotter, 2005). The national prevalence of visual stress is 12% and 46% within those identified with a specific learning difference, and this rises to 65% amongst the dyslexic population (Irlen, 1991).

Visual stress can cause some issues in both text and non-text reading. Dyslexia-friendly fonts e.g. Arial or Verdana and coloured paper can reduce this visual stress and allow students access to the mathematics. The use of bullet points, left justified text, better spacing or highlighted text partitioned into chunks can also be beneficial (Trott, 2003). Digital downloads of learning materials can be printed in the preferred font and paper colour.

The use of colour filters has been shown to diminish visual stress, and these can be in the form of text overlays, or lenses in reading spectacles. Numerous studies have shown that the preferred colour and tint of the filter varies with each case individual (Evans,
Irlen (1990) and Wilkins (1996) independently developed systems where a range of additive overlays can be used iteratively to find the optimum chromatic solution for a particular individual.

Visual stress is most commonly associated with dyslexia where the relationship with reading difficulties is most apparent. With dyscalculia it can affect the perception of symbols and numerals, causing misinterpretation and leading to elementary mistakes (Grant, 2013). In my study, four participants also had a form of visual stress, two with a co-occurrence of dyslexia.

**4.6 Co-occurrence of neurodiversity**

Co-occurrence refers to when an individual has been identified with more than one specific learning difference. In the medical model the term ‘co-morbidity’ is preferred, but Knivsberg et al. (1997) noted that not only does the term imply negative connotations, but it may also be incorrect; co-morbidity refers to the simultaneous existence of distinct medical conditions, whereas it is still unclear whether specific learning differences (SpLDs) are unrelated or collections of neurodiverse characteristics grouped into identifiable profiles (Pennington, 2006). With respect to dyscalculia, Desoete (2008) observed that co-occurrence of multiple specific learning differences is “more a rule than exception in children with mathematics learning differences“ (p15). Kaplan et al. (2001) suggested that neurodiverse individuals may be demonstrating various manifestations of a single impairment rather than discrete neurodiverseities. The term co-occurrence therefore implies a positive social model disposition and an acknowledgement that the neurodiverse characteristics could be attributable to more than one specific learning difference.

Identification of a specific learning difference is relevant for funding considerations. Funding for support from educational bodies is usually dependent upon a ‘label’ being matched to a student’s neurodiversity. Therefore traditionally it has been impossible for assessors to take a holistic view to neurodiversity (DePonio, 2004). Having ‘pigeon-holed’ a student within a particular single or co-occurring set of neurodiverseities, learning support practitioners must be careful to design a support program tailored for the student’s individual needs that result from their neurodiverse profile, and not based purely on the assigned specific learning difference.

As individual prevalence figures for each specific learning difference vary widely due to discrepancies in definition and how they are applied in randomised tests, measurement of the prevalence of a co-occurrence of two specific learning differences is highly inaccurate due to the increased potential error margin. For example a figure for the co-
occurrence of dyslexia from within the dyscalculic population varies from 11% to 70% (Gross-Tur et al., 1996; Barbaresi et al., 2005; Von Astor & Shalev, 2007).

4.7 Summary

This chapter formed the literature review that covers the wider domain of neurodiversity research. It discussed other common neurodiversities, notably dyslexia, and introduced the concept of co-occurrence, where an individual can be identified as having characteristics belonging to more than one neurodiversity.

I also provided a detailed explanation of the most recognised cognitive model for memory. Although much of this model is not relevant to this study, the aspect of working memory is a crucial component of neurodiversity research, and the memory model provides a background to general memory theory.

There are two other non-neurodiversity effects that could have an impact on individuals’ understanding of mathematics: mental health and visual stress. Mental health in this context mostly concerns mathematical anxiety, which is a common phenomenon that is strongly correlated with dyscalculia. Visual stress is often associated with dyslexia. Any student with mathematical difficulties should be assessed for these two issues which could present with dyscalculic-like characteristics.
5 Higher education

5.1 Introduction

This chapter describes the current process for identifying and supporting dyscalculia in higher education (HE). As there is little literature that looks specifically at dyscalculia, the chapter takes a broad view and describes both the general learning support environment and the support mechanisms for dyslexic learners where parallels with dyscalculia can be drawn.

The history of the legislation that covers all neurodiversities, and how these regulations define the responsibilities of higher education institutions (HEIs) is useful background information and is attached in appendix N. Using Loughborough University as an example, I describe the structure of one HE learning support centre, along with the processes for screening, formal identification, needs assessment, and allocation of support. I go on to examine the identification of dyscalculic students in more detail by reviewing the current procedures adopted by Educational Psychologists (EPs). Finally I look at literature discussing the subject choices of dyscalculic students, and fitness-to-practise, two areas that were shown to be particularly relevant within my study.

5.2 General reasonable adjustments

Reasonable adjustments in the Equality Act (Parliament, 2010) refer to implementation of new practices which are designed to ‘level the playing field’ and allow neurodiverse students to demonstrate their academic abilities and maximise their potential. A reasonable adjustment in HE is a “necessary accommodation or alteration to existing academic programmes, offering individuals the opportunity to demonstrate their abilities” (Association of Dyslexia Specialists in Higher Education (ADSHE), 2007, p3). Section 20 of the Equality Act defined the concept of making reasonable adjustments, and categorised three areas of duty:

- Provision, criterion or practice
- Physical features
- Auxiliary aids

‘Provision, criterion or practice’ defined academic procedures and practices. For example, the provision of lecture notes in a variety of formats (Herrington & Simpson, 2002).
Physical features concern the ergonomic environment of the education setting, such as wheelchair access or adjustable height benches in laboratories (Pavey et al., 2009).

Auxiliary aids are defined as external applications and services, for example computer screen-reading software for students with a visual impairment.

Hatcher et al. (2002) contended that not only should HEIs respond to disadvantaged students needs, but that they should implement measures in advance in anticipation of neurodiverse students (Reid, 2009).

5.3 Reasonable adjustments for dyslexia

Much of the current thinking around reasonable adjustments for SpLDs has evolved from research into dyslexia support, as this is the most widely recognised neurodiversity (British Dyslexia Association (BDA), 2013) and the first SpLD to be identified (Wagner, 1973). By looking at the wealth of research into dyslexia, and the history of growing acceptance for dyslexia support (Lawrence, 2009), parallels for dyscalculia and other neurodiversities can be sought.

Reasonable adjustments within HE have been considered contentious due to the prestige of a degree qualification, and concerns that requests for reasonable adjustments for dyslexic learners threaten to compromise academic standards (Riddell & Weedon, 2006). The area of examinations was particularly problematic, with Riddell and Weedon, following the social model (Oliver, 1990), claiming that “traditional forms of assessment are fundamentally discriminatory and that the onus lies with the institution to find new forms of assessment which will no longer penalise students with learning difficulties” (Riddell & Weedon, 2006, p58). The Equality Act (Parliament, 2010) makes no requirement for an HE institution to make adjustments to the competency standard itself (known as the benchmark statement), as neurodiverse students are still expected to show evidence of academic competence, knowledge and understanding. However the QAA noted that this “duty does apply to the assessment of that standard, that is, to the process of enabling a student to demonstrate that they meet the standard” (Quality Assurance Agency for Higher Education (QAA), 2010).

Research examining the difficulties faced by dyslexic students in HE led to the development of a suite of reasonable adjustments (Miles & Miles, 2004; Singleton et al., 1999; Hunter-Carsch & Herrington, 2001) that have filtered into learning support practice. These adjustments include practical measures such as extra time in examinations to allow for slow cognitive processing, reading difficulties and speed of writing, whilst others have been increasingly sophisticated, using advances in modern
technology such as mind-mapping software or digital recorders. Locally available reasonable adjustments are detailed on each HEI’s website, in accordance with the Special Education Needs and Disabilities Act (SENDA) (Parliament, 2001) that requires the publication of policies on provision (Pavey et al., 2009). A generic list of good practice can be found on the British Dyslexia Association (BDA) website (British Dyslexia Association (BDA), 2013), but not every suggestion will be appropriate for every student. Each student should have adjustments tailored to their individual needs since there are a number of different profiles of dyslexia (Taylor et al., 2009). The BDA recommendations are aimed at Needs Assessors (who recommend technology, study support and extra-time in examinations), lecturers (e.g. format of handouts, provision of lecture notes in advance) and learning support practitioners (e.g. techniques to help with study skills, time management and work organisation). Taylor et al. (2009) categorised four groupings of adjustments for the teaching of dyslexic learners in HE:

- Management of the transition from school/college/work to university
- Adjustments to teaching delivery methods
- Adjustments to assessment practices
- Adjustments to pastoral care

In many HEIs the learning support function works with academic departments to educate them around the needs of dyslexic students and how existing teaching and assessment practices can be modified to be more inclusive. For example allowing lecture notes to be downloaded in advance gives a dyslexic student the opportunity to print the information in an accessible format by adjusting the font type and size and using coloured paper.

5.4 Reasonable adjustments for mathematics

Numeracy support had until recently been based upon existing strategies for literacy support due to the lack of empirical data on how best to provide mathematical support. There had been little in-depth research for supporting dyslexic HE students with mathematical difficulties as most research has been focussed on dyslexic children who struggle with arithmetic (Chinn & Ashcroft, 1998; Henderson, 1998; Henderson & Miles, 2001). There are many components of dyslexia that could impact on mathematics performance, for example, working memory (Baddeley & Hitch, 1974), slow processing (Farmer & Klein, 1995), visual stress (Evans, 2001) and low self-esteem (Riddick et al., 1999). Despite this the link between dyslexia and mathematical difficulties has historically been under recognised (Malmer, 2000). Perkin and Croft (2007) used a case
study action research approach to identify a number of reasonable adjustments which may help dyslexic students with mathematics difficulties. These included:

- Tailored one-to-one support
- Squared paper in examinations
- Mind maps
- Colour overlays

The third and fourth suggestions could be applicable to any subject, but can be particularly useful in mathematics. Mind maps can be used to help break down the steps required to solve a complex problem, whereas colour overlays may be particularly useful when a student with visual stress is struggling to decipher mathematical notation. An understanding of neurodiversity is now a benchmark to good teaching practice in HEIs and is monitored by the Quality Assurance Agency for Higher Education (QAA).

In recent years software tools have been developed that are aimed at adult mathematics support. Unfortunately, Needs Assessors rarely recommend mathematics software as they are deemed to be subject-specific, and outside the scope of the Needs Assessment process. Examples of adult mathematics support packages are:

- Chatty-Infty (Infty, 2005) which is an editor of mathematics documents which uses the keyboard and simultaneous speech output. It was originally designed for visually impaired learners.
- TalkMaths (Kingston University, 2008) which is voice recognition software that is a plug-in to Dragon NaturallySpeaking. It provides a speech-driven user interface for creating and maintaining mathematical equations.

One-to-one study support for numeracy is another common reasonable adjustment offered to neurodiverse HE students. Figure 11 shows a breakdown of the current thinking around aims of tutors when supporting neurodiverse students with mathematical difficulties, taken from the Loughborough University Postgraduate Certificate Course for Mathematics Support and Dyslexia/Dyscalculia in FE/HE (see appendix H).

The diagram highlights the need to address both mathematical issues and emotional issues. Well-being issues such as mathematical anxiety (see section 4.4.1) can have debilitating effects preventing the student from effectively applying their own strengths as coping strategies. The ‘address mathematical barriers’ box is complex for dyscalculia support as it encompasses not only the intrinsic mathematical difficulties that are part of
dyscalculia, but the expected level of mathematical achievement demanded by the students’ HE course.

5.5 Support structures at Loughborough University

Every HEI should have access to learning support functions dedicated to providing appropriate help to neurodiverse students, in compliance with current legislation (some HEIs use external agencies). In this section Loughborough University is used as an exemplar to show the various responsibilities of HEIs and how they can be co-ordinated.

At Loughborough University the learning support function is predominantly the Counselling and Disability Service (CDS) which is supported by the Mathematics Learning Support Centre (MLSC), as shown in figure 12.

The CDS has a remit to provide support, advice and guidance to students with disabilities and SpLDs. It also works with staff to promote good practice and develop an inclusive environment (Loughborough University, 2013a), and is divided into six services, as detailed in table 4.
Figure 12 - Learning support structure at Loughborough University
Table 4 – Counselling and Disability Service structure at Loughborough University

The MLSC offers a range of services designed to support any student at Loughborough University in their learning of mathematics or statistics on an ad-hoc, drop-in basis. In particular, it aims to help students in the early stages of their studies to benefit from resources and tuition over and above that normally provided as part of their programme (Loughborough University, 2013b). The Eureka Centre for Mathematical Confidence has strong links with the CDS and plays a part in the process of identifying and supporting students with a mathematical learning difference. It offers more dedicated, one-to-one support than the MLSC. Examples of this include:

- Drop-in for a confidential chat
- Help with revision techniques
- Improvement of study skills in mathematics
- Support to cope with examination stress
- The opportunity to meet other students with similar concerns
- Quiet workspace
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The MEC also ran a postgraduate certificate course to train tutors in FE or HE institutions to support students with mathematical difficulties due to dyslexia or dyscalculia (see appendix H).

5.6 Support process

In order for a student to receive reasonable adjustments, there is an established process in HE. This section describes this process, notated with specific examples from Loughborough University (see figure 13). There are two routes through which a student may enter the support system: students who arrive at university with a pre-existing disability or SpLD disclosure, and those who are only identified after arrival. Roughly 40% of students who will receive reasonable adjustments arrive at Loughborough University with a pre-existing identification. This information regarding disability will arrive via the Universities & Colleges Admissions Service (UCAS) form or an email directly from the student. In both cases supporting evidence is required. CDS then invites the student for a meeting to start the process for applying for a disabled student allowance (DSA). Here the needs of the student are discussed and the evidence of the student’s disability or SpLD is examined. The DSA approval requires recent evidence (evaluated within the last five years) in the form of a diagnostic assessment from an Educational Psychologist (EP) or suitably qualified assessor. Students with outdated documentation will need updated evidence or no support is possible.

Students with no pre-existing identification often become aware of their difficulties due to the increased demands of HE. Alternatively, they may already be aware of a difficulty, but find that their existing coping strategies are no longer adequate since the nature of the learning environment is different and requires more independent learning. The decision to seek help will come directly from the student, possibly after advice from a friend, lecturer, parent or personal tutor, or through disseminated publicity materials.

The preferred first point of contact for any existing student seeking help is CDS, but a request for help may arrive at any part of the organisational structure (see figure 12). This is more often the case with a mathematical learning difference, where it is likely a student will approach the MLSC or Eureka directly. All unsolicited student approaches are welcomed and coordinated appropriately to provide an efficient response and a secure and familiar point of contact.

5.7 Dyscalculia screening

On enquiry, the student will be asked to undertake a screening, either with SSS (reading, writing, memory and study skills issues) or the Eureka Centre (mathematical difficulties).
On initial contact the underlying cause has generally not been identified, and an SpLD associated with reading or working memory such as dyslexia could be the cause of any mathematical problems. Screening involves a selection of standardised psychometric tests that look for indications of known SpLD traits.

<table>
<thead>
<tr>
<th>Screening Tool</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dyslexia</strong></td>
<td></td>
</tr>
</tbody>
</table>
| LADS (Lucid Adult Dyslexia Screening)  
Developed by Singleton et al. (2002)  
Available from Lucid Research | Adult based  
Phonological processing  
Working memory  
Lexical access  
Nonverbal reasoning module |
| DAST (Dyslexia Adult Screening Test)  
Developed by Fawcett & Nicolson (1996)  
Available from Pearson Assessment | Adult based  
Rapid naming  
One-minute reading and writing  
Postural stability  
Phonemic segmentation  
Two-minute spelling  
Backwards digit span  
Nonsense passage reading  
Non-verbal reasoning  
Verbal and semantic fluency |
| BDT (Bangor Diagnostic Test)  
Developed by Miles (1983)  
Published by University of Bangor | Laterality (left-right body parts)  
Repeating polysyllabic words  
Subtraction (mental arithmetic)  
Times tables  
Months forwards / backwards  
Digits forwards / backwards  
Letters “b”-“d” confusion  
Familial incidence |
<p>| <strong>Dyscalculia</strong> | |
| Butterworth Screener | Child based to age 14 |</p>
<table>
<thead>
<tr>
<th>Developed by</th>
<th>Test Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butterworth (2003)</td>
<td>Simple reaction time, Dot enumeration, Number comparison, Arithmetic achievement test</td>
</tr>
<tr>
<td>Beacham &amp; Trott (2005)</td>
<td>Adult based, Excludes other SpLDs, Conceptual operations, Inferential operations, Abstract symbolic operations, Spatial-temporal operations, Graphical operations</td>
</tr>
<tr>
<td>Vernon, Miller &amp; Izard (1995)</td>
<td>Aged 11 to adult, Open questions, Skills profile reflects the National Curriculum attainment targets</td>
</tr>
<tr>
<td>Jastak &amp; Bijou in 1941</td>
<td>Mastery test, All ages, Evaluates word reading, Evaluates sentence comprehension, Evaluates spelling, Mathematics computation, Learning, behavioural or vocational difficulties</td>
</tr>
<tr>
<td>Klein (1995)</td>
<td>Interactive interview to record life accounts that support identification.</td>
</tr>
</tbody>
</table>

**Table 5 – SpLD screening tools used in HE**
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Often the SSS or a Eureka professional will use their expertise to mix and match the tests to provide a more thorough and adaptive screening process. Table 5 shows some of the most commonly used tests for dyslexia and dyscalculia. To test specifically for dyscalculia, the Eureka Centre uses DysCalculiUM, a software package developed in-house by Beacham and Trott (2005) due to the need for a fit-for-purpose adult-based dyscalculia screener. DysCalculiUM is now commercially available through the learning support software house Tribal (2010), in conjunction with a diagnostic interview to capture the history of the student’s neurodiversity and everyday life difficulties.

Drew and Trott (in press) claim that it is essential to use a diagnostic interview (DI) in conjunction with any test-based screening process, as many SpLD definitions refer to difficulties in childhood and everyday experiences (World Health Organisation (ICD-10), 1992; American Psychiatric Association (DSM-5), 2013), which cannot be captured adequately by a fixed, non-interactive test. A diagnostic interview for dyscalculia can explore with the student those mathematical topics they find difficult and when this first occurred. Drew and Trott (in press) claim that the diagnostic interview is a necessary part of the screening process as it captures the holistic picture of the student.

The DI obtains, through a series of semi structured questions, a full history and background and covers all areas of potential issues. The DI can be used to establish a picture of strengths and weaknesses from the student’s own point of view, and provide a holistic profile. A DI is also important as it gives the student a chance to reflect upon their neurodiversity; this is often the first time that a student has ever talked at length about their difficulties.

If the results of this screening are positive, i.e. show evidence of an SpLD, the student is assessed by an Educational Psychologist (EP). Loughborough University has a set of regularly used EPs, some of which are independent and some employees of third party companies. Unfortunately this has a cost implication for the student in the region of £300 to £600 per assessment as the assessors are external to the University (CDS, 2013). Without an official identification of this type, the student would be ineligible for Disabled Students Allowance (DSA). For some students, the cost is prohibitive, and other finance streams such as the Access to Learning Fund (ALF) can be explored through student finance. As SpLDs are classified as a disability by the Equality Act (Parliament, 2010), some students are dissuaded from taking this route, for fear of labelling and stigmatisation. At the time of writing this process is being reviewed by the government and subject to reorganisation.
Figure 13 - Learning support process for SpLD students at Loughborough University
An EP meeting with the student takes about two hours, and the EP will test the student for a number of known SpLDs. Currently there is an issue that dyscalculia is not well understood by many EPs and some feel unable to identify it. EPs often report an identification of dyslexia and/or dyspraxia with ‘mathematical difficulties’, which although enough to qualify for DSA, is not helpful in understanding the root cause. EPs can also find it difficult to recognise when a student is dyscalculic-only, or has a co-occurrence of other neurodiversities (see section 4.6). Once the full report is received a meeting is held with the student at CDS to discuss the findings. Staff at SSS or Eureka will help the student interpret the report. If an SpLD is indicated, then with the approval of the student, an application for DSA funding will be submitted to the appropriate financial body (Student Finance England, Student Finance Wales, Northern Ireland Libraries Board, Student Awards Agency for Scotland, or sponsor, e.g. NHS). As this may be a lengthy process, some cost-free arrangements can be put in place immediately, such as extended exam times.

When DSA approval is granted, the student will meet with the National Network of Assessment Centres (NNAC) to discuss the level and type of support required. The student can choose any centre nationally that is convenient to them. Typically at Loughborough’s Needs Assessment Centre (NAC) waiting time for an appointment is approximately two weeks. The needs assessor discusses the options available based on the EP report, and creates an assistance package which could include technology (e.g. laptop, specialist assistive technology software), extra privileges (e.g. extended time in exams, photocopying allowance), a note-taker or one-to-one support. The NNAC assessor must then submit a plan, with costing, to the student within ten working days (in accordance with guidelines of the DSA quality assurance group). The student can suggest changes as appropriate. This document is then sent to the financial body for approval and typically could take over a month to process. The financial body will then write back, stating which elements of the assistance package they have agreed to fund. A process of negotiation can take place if the NNAC assessor and student feel that any omissions are unfair. The HEI is then responsible for the provision of the assistance. Invoices for student support, mentor time and other agreed expenses are sent directly to the appropriate funding body.

5.8 Dyscalculia assessment

Although screening can give a good idea of whether a student has an SpLD, a student can only be given an official identification through the assessment process. In the UK, a neurodiverse HE student must be officially identified with an SpLD label as defined by
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DSM-5 (American Psychiatric Association (DSM-5), 2013) to be legally entitled to funded additional support. Labels can have both positive and negative effects as they could open doors to support, or be a catalyst for stigmatisation (Lauchlan & Boyle, 2007). For a student of HE to be officially identified with an SpLD they must be assessed by an educational psychologist (EP) or other qualified assessor. The assessment tools are designed to measure a variety of cognitive processes, such as speed of processing and working memory.

Wiles (2002) raised the issue of whether HE assessment was discriminatory against neurodiverse students, notably dyslexics; multiple choice questions, which are commonly used in mathematics assessment, can be difficult for some dyslexics as they rely on accurate comparison of the calculated answer to the written answer.

Although the assessment criteria for dyscalculia identification follow a deficit model, Grant (2009) described how this process can be a positive experience, as it has the potential to be “both empowering and enabling” (p33). An assessment can make the student aware of their own neurodiverse characteristics and how they affect their academic and everyday life, allowing for the adoption of coping strategies and increased self-esteem as they realise there is a reason for their differences.

Neurodiverse profiles are complex and cannot be fully understood or described by a generic label, even though the name of the neurodiversity is required by various funding bodies to allow for financial support. Assessment therefore concentrates on the strengths and weaknesses of the student by comparing cognitive attributes relative to the expectation of a neurotypical learner. These variations give rise to a map of peaks and valleys, which are referred to as the neurodiverse “spiky profile” (Grant, 2009, p52). A particular configuration of spiky profile may be strongly related to a certain SpLD, but this should form only a guideline, as neurodiverse students sharing the same identification may display dissimilar strengths and weaknesses. Therefore the focus on a neurodiverse student should always be related to their own personal spiky profile, and not the generic profile of the SpLD label. Grant (2009) argued that understanding how the student’s neurodiversity affects academic and social situations is the key to implementing interventions that can bring about positive life changes. These social interactions can only be captured by the use of a diagnostic interview (Klein, 1995; Drew & Trott, in press).

The educational psychologist assessment includes tests for a variety of cognitive characteristics, such as reading accuracy, spelling, mathematics computation, verbal comprehension, working memory, perceptual reasoning and processing speed. Many of
these attributes are not related to dyscalculia, but need to be assessed to provide a complete neurodiverse profile, and possibly rule out alternative reasons for mathematical difficulties beyond dyscalculia. Figure 14 shows a possible profile of a dyscalculic student. Note that mathematics computation, as discussed in section 3.3.1.1, must address the conceptual understanding of mathematics, and not just the ability to perform arithmetic calculations.

![Possible profile of student with mathematical difficulties](image)

*Figure 14 – Example spiky profile of a potential dyscalculic student (Grant, 2013b)*

A problem with working memory, as discussed in section 4.2.2, is not an indicator of dyscalculia, but may be evidence of mathematical anxiety, or possibly an unrelated neurodiverse weakness. Grant (2013b) argued that a key component to the assessment of dyscalculia is the intelligence disparity criterion (see section 3.3.1.4), but he chose to use perceptual reasoning as the benchmark intelligence measure rather than general IQ. Perceptual reasoning measures the ability to comprehend non verbal stimuli to solve logic-style problems. For dyscalculia to be in evidence, Grant argued that the mathematical computation score on the assessment must be markedly less than the student’s perceptual reasoning skills score.

### 5.9 Subject choice and dyscalculia

There is little research in the field of HE subject choice, even with neurotypical learners, although Van de Werfhorst et al. (2003) found a strong relationship between subject grade achievement in secondary education and a student’s chosen tertiary education
degree. Most previous research in the area of subject choice has focussed on the relationship with race, gender and social class (Reay et al. 2001; Reay & Ball, 2005; Hernandez-Martinez et al. 2008). There has been some exploration of the effects of neurodiversity and subject choice in HE with Grant (2009) claiming that dyslexic and dyspraxic students choose courses that minimise the need to write essays, remember number facts and take timed exams. Trott (2003) described from her experience in learning support practice, how dyslexic students in HE can be considered as either mathematically able, or as having mathematics difficulties. The first group are drawn towards physical science subjects where there is less language content, whilst the second more mathematics-averse group tend to choose social sciences, human sciences, economics or business studies. Trott (2003) stated that dyscalculic students, both with and without a co-occurrence of dyslexia, tend to avoid subjects that contain high mathematical content, but may choose subjects such as social sciences or human sciences if they are “unaware of the important role that statistics plays” in these courses (p18).

Weiss at al. (2012) suggested that indecision around postsecondary choices may be due to lack of careers support for students with a learning difference, resulting in unsupported neurodiverse students not developing the “critical self-determination skills necessary to know what information is necessary, how the information can be used to set goals, and how support can be recruited in the general education curriculum” (p187). Although careers support was a factor only mentioned explicitly by one student in my study, all participants in my study described their mathematical difficulties as being a significant factor in their career or vocational choices (see section 8.3).

5.10 Fitness to practise

Vocational issues around fitness-to-practise have led to the development of dyscalculia-specific literature that has examined reasonable adjustments. In the health profession, MacDougall (2009) drew attention to dyslexia and dyscalculia as two potentially unrecognised conditions among undergraduate medical students, in response to reports that have highlighted issues with medical professionals struggling with drug dosage calculations, monitoring fluids and reading charts (Banning, 2006; Glaister, 2007). Kirk (2012) argued that it is possible to become a dyscalculic nurse if you are aware of your limitations and then with co-author Payne (2012) recommended some reasonable adjustments for dyscalculic student nurses. They did however acknowledge that it remains contentious within nursing as to whether “reasonable adjustments may be enough to balance the conflicting requirements of legislation, and duty of the profession
to safeguard the public” (Kirk & Payne, 2012). This is a key issue and discussed further in chapter 12.

The primary purpose of regulation within the healthcare professions is to protect the public (Nursing and Midwifery Council (NMC), 2014). The need for accuracy in such things as drug calculation necessitates a reasonable level of mathematical competence in practitioners. There is debate around what level of competence this should be and what constitutes reasonable adjustment for practice. There already exists a culture of concern about whether dyslexic health practitioners with mathematical difficulty should be permitted to administer drugs, and this situation has been exacerbated with the increasing awareness of dyscalculia (see section 12.3).

Wright (2000) described a perception amongst healthcare practitioners that dyslexic students were likely to practise unsafely, despite evidence showing that well supported dyslexic students can become safe and competent practitioners. Murphy (2009) claimed that this perception has created a negative impression of dyslexia where the corresponding strengths of the neurodiversity were rarely acknowledged. Kirk (2012) suggested that educators may feel that dyscalculic nurses involved with medicine management pose a similar threat to patient safety.

Fitness to practise in the presence of dyscalculia is of particular concern to the HEIs that administer healthcare courses (MacDougall, 2009). The Nursing and Midwifery Council (NMC) (2006) defines fitness to practise as a nurse or midwife having “the skills, knowledge, good health and good character to do their job safely and effectively”. The ability to demonstrate the mathematical skills required to achieve competence is a pre-requisite to registration as a nurse or midwife in the UK (Sabin, 2001). Nursing and Midwifery Council guidance (2006) stipulates that healthcare practitioners must demonstrate safe and effective practice without supervision, but went on to say that this should not exclude disabled practitioners who are able to practice safely with the support of reasonable adjustments.

Morris and Turnbull (2006) found that dyslexic nurses were aware of their drug calculation issues and would re-check prescriptions and seek confirmation of accuracy from clinical mentors, in a strategy that became known as hyper-vigilance (British Dyslexic Association (BDA), 2014). They gave an example from a case study where a dyslexic nurse would re-check the dosage twenty times.

The fitness to practise issue was also raised in the domain of teacher training. In the UK, all trainee teachers must pass a numeracy examination, known as the qualified teacher status (QTS) test, irrespective of their chosen discipline. For example, a dyscalculic
prospective English teacher would still have to pass the numeracy test, which would be an enormous challenge and a significant barrier to achieving success. The issue of student teachers having poor numerical skills has been considered for some time (Goulding, Rowland & Barber, 2002), but only recently has it been recognised that many struggling students may be dyscalculic and need additional support (Matthews, 2009).

Fitness to practise for teachers is governed in England and Wales by the Department of Education guidance committee (Department for Education (DfE), 2011), which stipulates the need for teachers to make education of pupils their primary concern, act with honesty and integrity, and have strong subject knowledge which is kept up-to-date.

Although it seems unrealistic for a dyscalculic student to choose a STEM subject (Science, Technology, Engineering and Mathematics), a few cases are being identified, particularly in the field of Biosciences (Mann, 2012). It is likely that some dyscalculic students at secondary school have developed sophisticated coping strategies and have felt confident to tackle overt mathematics content in an HE course (see section 8.3.2). This can lead to a demanding support scenario for the institution when the student begins to struggle. STEM departments at some HEIs are acting proactively to raise awareness amongst staff and share best practice to help these students (Institute of Physics, 2010; Higher Education Academy, 2012).

5.11 Summary

This chapter formed the literature review for learning support within higher education and current legislation and processes for supporting dyscalculic students. Every HEI is different in the implementation of learning support, so Loughborough University was used as an example. I also listed the current reasonable adjustments employed for neurodiversities in general and mathematical difficulties in particular.

As subject choice and fitness to practise were two strong themes to emerge from the data, I discussed the existing literature that deals with these topics.
6 Methodology

6.1 Introduction

Denzin (2005) stated that “theory, method and epistemology are aligned” (p944). Therefore the components of a research study must be both compatible and complementary, to allow data to emerge without methodological contradictions. This chapter in conjunction with chapter 2 (Theory) covers the four basic components of the research process: epistemology, theoretical perspective, methodology and methods (Crotty, 1998), as well as the sampling strategy and ethical considerations. Table 6 summarises the chosen methodological approach which I then discuss in each section, explaining the rationale for my choices.

<table>
<thead>
<tr>
<th>Theoretical perspective</th>
<th>Methodology</th>
<th>Data collection methods</th>
<th>Data analysis methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory (epistemology)</td>
<td>Interpretive grounded theory</td>
<td>Semi-structured interview</td>
<td>Thematic analysis</td>
</tr>
<tr>
<td>Social model of disability</td>
<td>Qualitative research</td>
<td>Learning support tuition (participant as researcher)</td>
<td>Pollak categorisations</td>
</tr>
<tr>
<td>Theories of neurodiversity</td>
<td></td>
<td></td>
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</table>

*Table 6 – Summary of methodological approach*

The methodological approach defines the structure of the study and determines the choice of methods, data collection instruments and analysis techniques. As my research questions focus upon dyscalculia from the perspective of those who live with the neurodiversity, it was clear that a qualitative approach was appropriate to allow for in-depth descriptive data to emerge. The purpose of qualitative research is to interpret the world by uncovering the meaning bestowed on it by its population. Denzin and Lincoln (1994) claimed that:

*Qualitative research is multi method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them (p2).*

This definition emphasises the importance of interpretation; this is not just a description of the study domain, but a basis upon which researchers can develop theories to represent the complexity of the social world (Hammersley, 1981).
I have chosen a grounded theory methodology over other qualitative approaches, as this allowed for a more analytical study design, incorporating different data sources, rather than a purely interview-based descriptive approach, such as phenomenology. However my interpretation of grounded theory would be described by a number of researchers as an adaption of grounded theory or even ‘grounded theory-lite’ (Oliver, 2011), as I have chosen to ignore some of the more positivist aspects of the framework that were initially described by Glaser (1978). A full grounded theory approach involves the implementation of a full set of sampling and procedures, with the goal of creating theory from the data. An adapted grounded theory approach uses the same methods for producing categories and concepts, but is less strict on the framework and the need to derive theory (Pidgeon & Henwood, 1997). This is probably the most commonly adopted form of grounded theory (Oliver, 2011). In section 6.3 I discuss how this approach is both valid and a common approach for modern researchers of social science.

An ethnographic approach was considered, as the principles of ‘telling the story’, or ‘letting the voices be heard’ of marginal or less visible members of society (Somekh & Lewin, 2004) would have suited my research questions. In addition, exploration of the “shared beliefs, practices, artefacts, folk knowledge and behaviours of a people or group” (Goetz & Lecompte, 1984, p2) would have complemented a socio-cultural framework. However logistical difficulties would not allow me to observe the world of the participants directly, beyond practice that takes place within the learning support environment. As my methods were limited to participant interaction within a controlled setting, an ethnographical approach would have been hard to justify.

A case study methodology would have been a possibility, but I was unable to formulise an appropriate case definition. The participants were not individual cases, as my research questions focussed on the nature of dyscalculia, and how this is perceived by the dyscalculic students. I was unable to consider dyscalculia itself as a case as it cannot be delimited within a boundary by a selection of participants.

Yin (2003) observed that propositions can be helpful in a qualitative study, but are not a pre-requisite. They equate to hypotheses in quantitative approaches in that they make educated guesses about the outcomes of research data. Each proposition serves to focus the data collection and determine the direction and scope of the study (Miles & Huberman, 1994). Due to the adoption of a grounded theory approach (Glaser & Strauss, 1967), no propositions were made, and any deductions emerged from the data without prior conjecture.
6.2 Interpretive grounded theory

Grounded theory can be defined as "the discovery of theory from data systematically obtained from social research" (Glaser & Strauss, 1967, p2). While it was originally developed as an analytical method for social science, it has since been applied to numerous disciplines, such as health and education sectors (McCallin, 2003; Kirchhoff & Lawrenz, 2011), and has arguably been "the major contributor to the acceptance of the legitimacy of qualitative methods in applied social research" (Thomas & James, 2006). Glaser and Strauss (1967) proposed their theory as a practical technique for focusing on the interpretive process by examining the "the actual production of meanings and concepts used by social actors in real settings" (Gephart, 2004, p457). As my research questions focus on the nature of dyscalculia, rather than just a description of the participants' experiences, it was vital that I chose a methodology with the potential to facilitate an understanding of how dyscalculic students perceive mathematics within their social world and their own neurodiverse identity. This methodology is well suited to research which seeks to understand groups where there has been little exploration of the contextual factors that affect people's lives (Crooks, 2001). It allows the researcher to look beyond conjecture to illuminate the underlying processes (Glaser, 1978). What little current dyscalculia research is available has been concentrated within neuroscience, with little regard to the effects of social implications to dyscalculic individuals and their own perceptions on living with the neurodiversity. A grounded theory approach has been able to explore these social factors and find commonalities in the participant's narratives to create group meaning, despite the fact that dyscalculic students may rarely have the opportunity to interact socially with each other.

One advantageous feature of grounded theory is that it provides a methodical structure to a research process that can otherwise be difficult to define. Thomas and James (2006) stated that:

While qualitative inquiry is absolutely valid, it is difficult to do. In education it may involve talking – as naturally as possible – with students, parents, teachers; it may entail taking part, watching and listening, in schools and other environments. But when all this is done, what comes next? (p2)

This methodological structure is provided by a system of rigorous thematic analysis and categorisation of codes. By identifying patterns in the coded data, themes emerge that inform the development of new theories. Interpretive grounded theory operates in reverse to positivist research methodologies, as data collection is performed before any consideration of a hypothesis (Glaser & Strauss, 1967), which is in contrast to Yin's (2003) argument for qualitative propositions. Although my intention was to have no prior
expectations about findings, I have had to acknowledge that some preconceptions do exist. My research questions had already created a structure for my findings, and have influenced the way I have interpreted the results. A full description of this analytical process can be found in the methods section (see section 6.5.3).

6.3 Adapted grounded theory

Since the creation of grounded theory almost fifty years ago, many researchers have chosen to modify some of the principles to make the methodology applicable to varying fields of research. Although some purists may criticise the approach, this pragmatic implementation of grounded theory combined with different theoretical positions is now widely supported and justified (Scott, 2005), and is the approach that I have taken for my research.

Glaser and Strauss (1967) originally conceived grounded theory as a methodology that was independent of any theoretical perspective. Crotty (1998) argued that this supports the "epistemological view that things exist as meaningful entities independently of consciousness and experience... that they have truth and meaning residing in them as objects" (p434). This is in contrast to my own epistemological position as a socio-cultural theorist. Although Glaser (1978) felt that the application of an external theoretical framework could corrupt the analysis and force erroneous meaning on to the data, Strauss and Corbin (1998) offered an alternative view to the inductive approach of Glaser by referring to the 'construction' as opposed to the 'discovery' of grounded theory. This opened the door for external theoretical frameworks to be married with grounded theory to produce interpreted meaning that has both emerged from the data without prejudice, and allies itself to a pre-existing view of how the world is constructed.

Charmaz (2006) concurred by stating that researchers "can use basic grounded theory guidelines with twenty-first century methodological assumptions and approaches" (p9). Grounded theory therefore evolved from a rigid to a more flexible process, allowing the facilitation of diverse theoretical viewpoints, such as feminism, Marxism and phenomenology (Charmaz, 2000). Oliver (2011) described how grounded theory has been flexible in evolving over a number of years to the needs of critical realist inquirers and linking research more firmly with practice, and critical realism shares some aspects of sociocultural theory in a belief that an understanding of reality must be mediated through the "filters of language, meaning-making and social context" (Bhaskar, 1986, p72). Clarke (2003) claimed that interactionist theory and grounded theory could be combined into a coherent valid approach.
Chapter 6 - Methodology

This reaffirms that my choice to merge interpretive grounded theory with socio-cultural theory is valid, particularly as the two have been married together successfully in previous research (Seaman, 2008). The grounded theory approach allowed themes to emerge without, or with little bias, in terms of the factors which dyscalculic students deem to be important in relating their life stories and constructing meaning around the nature of dyscalculia from a neurodiverse perspective. The socio-cultural theory then allowed these themes to be examined from the aspect of socially embedded learning.

My methodology was still rooted in grounded theory (as opposed to a just utilising a thematic coding method) as I was still allowing for the possibility of any theory on dyscalculia to emerge. Although my study of fourteen participants would not be generalisable to a dyscalculic population, the approach did allow for any commonalities to emerge that could form some embryonic constructs. Examples of this are the ideas on non-cardinality (see section 9.3.5) and categorisation of dyscalculic HE students (see chapter 11) that have emerged from the data without prior hypothesis.

The methods associated with the grounded theory approach, notably theoretical sampling, open coding, constant comparisons, memos, diagrams, axial coding and theoretical saturation were all used, or at least attempted, as part of the data collection and analysis processes (see section 6.5.2 & 6.5.3). Open coding and constant comparisons, which are important elements of full grounded theory, were adhered to strictly to allow for the emergence of any theory, if possible, given the small necessitative sample.

6.4 Ethics

Before commencement of the study ethics approval was sought from the Ethical Advisory Committee of Loughborough University. As the dyscalculic students could be considered as ‘vulnerable’ students, a level of ethical approval was expected above that which is normally required for qualitative research within the Mathematics Education Centre.

The purpose of the ethical approval process was to guarantee that the rights and well-being of the participants remained paramount. Each participant had the option of a chaperone which could either be a friend or their learning support tutor. In eventuality none of the participants chose this as an option. Participants were given detailed information about the project aims and methods so they could make an informed opinion on participation. This information was conveyed by the participant information sheet (see appendix C). Particular care was taken to ensure that all participants understood the consent forms and the scope of the research. This was achieved by discussing each paragraph in turn and by asking for feedback from the participant on each point. As a
researcher I was aware of the risk that participants may become distressed in talking about difficult events in their life and was prepared to stop the interview at any time and allow the participant to take time out or withdraw from the process. The project complied with the withdrawal of data guidelines by allowing any participant to withdraw from the study, with no questions asked, at any point up to publication. During the pilot interview process (see appendix J) I chose to end one interview prematurely as the participant was becoming emotionally upset. All information divulged by the participant was held in the strictest confidence and only shared between myself as the researcher and my supervisor.

The recorded audio data was captured digitally and copied to a password-protected folder. Original device recordings, hardcopy printouts or hand-made notes were held in a locked drawer at Loughborough University. Participants’ details, such as contact information, were held in a separate secure location for extra security, either in a different password protected file (digital) or locked drawer (physical). All references to participants and institutions in the thesis and subsequent publications and presentations were anonymised.

The signed off ethical approval form contains a full list of ethical considerations and the relevant steps required to ensure compliance.

6.5 Methods

This section describes the methods that were employed for collecting and analysing data, why they were chosen and how they were implemented.

6.5.1 Data collection

Two methods were employed for collecting data. The first was a traditional semi-structured interview with dyscalculic students as the participants, and the second involved production of a personal reflective account after I took on the role of a tutor within a mathematics learning support centre.

A focus group was considered as it would allow dyscalculic students, who are unlikely to meet in everyday circumstances, to share experiences and provide a rich source of data containing collaborative meaning. This method was dismissed for logistical reasons; the scarcity and distribution of potential participants meant that to bring them together in sufficient numbers for a focus group would be impractical within the limitations of this study.
6.5.1.1 Interviews

I chose individual interviews as the primary method of data collection. The qualitative research interview seeks to reveal the inherent meanings of the world of the participants (Kvale, 1996). Seidman (2006) described the interview process as an "interest in understanding the experience of other people and the meaning they make of that experience" (p3).

Although my chosen methodology was not an ethnographic approach, I wanted to retain some of the story telling aspects of that paradigm and allow the ‘student voice’ to remain central. Hill et al. (2005) described the tensions between allowing participants to lead the discussion and identify their own areas of interest, whilst ensuring that the research questions are addressed. DiCicco-Bloom and Crabtree (2006) cautioned that interviewers must remain open-minded and allow the participant to define the direction of conversation. With the emphasis on this study being on the expression of the student voice, it was vital that the interview process offered the freedom to explore important topics as defined by the student. Conversely, in order to ensure some uniformity with which to provide a basis for comparison, I felt that some sort of topic guide was appropriate. Whilst a structured interview would provide uniformity of discussion topics, its restrictive design was incompatible with a grounded theory approach. These requirements for the interview format dovetailed effectively into a semi-structured approach which then led to the development of an interview schedule (see appendix E).

Flick (2002) characterised an interview schedule as a protocol created to serve as a guide. Use of such a protocol does not preclude the addition of follow-up questions where appropriate. I conducted interviews using Spradley’s (1979) conception of a “friendly conversation into which the researcher slowly introduces new elements to assist informants to respond” (p58).

Each interview was designed to last for approximately sixty to ninety minutes in length. The interview schedule was trialled in three pilot interviews, the results of which are discussed in appendix J. I conducted all the interviews within the participants’ own higher education institutions to provide a familiar, non-threatening environment for the student and minimise the burden of participation, particularly mathematical anxiety.

6.5.1.2 Learning support tutor participant observation

As I was new to the domain of learning support in higher education, and in particular dyscalculia research, I chose to enhance my understanding of the learning support process and neurodiversity by supporting two neurodiverse students. I worked with each
student for at least eight hours over a period of several weeks. This allowed me to develop strategies of scaffold support, in response to the direction of study set by the student. I was also able to consolidate my academic knowledge of neurodiversity in a practical context. I chose to work with a dyscalculic student and dyslexic student with mathematical difficulties, to help formulate my own understanding of the similarities and differences between these two neurodiversities. Each session was audio recorded and samples of written work were photocopied. In addition I kept field notes and recorded observations and reflections in a diary.

![Figure 15 – Adopted role in learning support method](image)

This method involves participating in a real-life activity with the neurodiverse student in a natural setting. Although this could not be described as an ethnography, it was necessary to situate myself methodologically as a participant researcher, where I occupied roles of both researcher and participant simultaneously within the learning support activity. Gold (1958) discussed the potential roles for a participant researcher as “a range of flexible positions in a continuum of participatory involvement” (p106), from a ‘complete observer’ to a ‘complete participant’, and this participatory spectrum is relevant to all research methodologies. My first adopted position as a ‘complete researcher’ for the interview method was in contrast to my second method position of ‘participant as researcher’. When gaining consent for the learning support element of the research, I checked that the students involved understood my role. My primary function within the learning support process was that of a tutor, with a remit to facilitate the students’ understanding of mathematical concepts encountered in their course curricula.
This allowed me to maintain legitimacy within this role as well as gather data by observing the participants as they performed mathematical tasks. The content of the sessions was driven by the students as part of a mutually agreed programme of learning support, which helped provide legitimacy to my primary role as a learning support tutor rather than a researcher. Figure 15 shows how my adopted role is positioned to observe a small aspect of the dyscalculic student’s life within higher education.

This practice of observing participants whilst primarily providing mathematical support situated my role as that of ‘participant as researcher’ within Gold’s taxonomy (1958).

6.5.2 Sampling for interview

I recruited participants to the pilot phase of the study from local students that were known to my supervisor (see appendix J). For the main study a convenience snowball sampling strategy (Biernacki et al. 1981; Noy, 2008) was employed to target a difficult-to-reach limited population. Learning support practitioners were asked to perform as gatekeepers (Morse & Field, 1995) as they had knowledge of and access to dyscalculic students, and would be able to directly assess their suitability for participation. Details of the implementation of the sampling process can be found in section 7.2.

All participants, and their learning support tutors where applicable, were sent either an invitation letter or a full project pack. This pack contained a project summary, ethical approval details (see appendix C), consent forms (see appendix D) and the interview schedule (see appendix E).

6.5.3 Analysis

Each interview was audio recorded with the permission of the participant and transcribed either personally or using a third party transcription service. I notated the transcriptions with body language and contextual information that I had captured in my field notes, to try and redress criticisms that purely audio transcriptions do not contain the social, temporal, and spatial data that is part of the interview process (Kvale, 1996). Lapadat and Lindsay (1999) observed that the “difficulty rests in researchers’ unreflective assumption that oral discourse can be transformed into written text without consequence” (p74). Transcribing audio data is part of the analytical process as it is “open to multiple alternative readings, as well as reinterpretation with every fresh reading” (Poland, 1995, p292). As my research was focussed on stories and content, rather than a discourse-based study, I decided that it was not important to keep every utterance exactly how it was presented, as long as the flow of the text remained intact. Therefore natural hesitations, repetition, and slang (e.g. ‘like’, ‘sort of’) that are
commonplace in everyday conversation were not retained in the transcription to allow the narrative to become more readable and the story clearer. Where I interpreted that the manner of talk indicated an underlying emotional response to the subject matter, rather than being colloquial speech, I notated this within the transcript.

The adapted grounded theory approach uses a technique of textual thematic coding to allow themes to emerge. The unit of analysis for this method is the amount of text that is considered when applying a code, and could be a single word or single line of text in a discourse-based analysis. For this study I chose a paragraph of text, including the interviewer’s question where applicable. This was to allow the full narrative around a comment to remain attached so that the context of the coded text could be understood when isolated from the narrative. Choosing a comparatively large unit of analysis resulted in text being assigned to more than one code. Although this technique was not part of original grounded theory (Glaser & Strauss, 1967), many researchers since have supported this strategy (Strauss & Corbin, 1998; Miles & Huberman, 1994).

Open or substantive coding was the first coding process I employed where each unit of textual analysis was inspected and each different concept was highlighted (Strauss & Corbin, 1990). Using the principles of grounded theory, themes were not searched for, but allowed to emerge from the text.

Axial coding (Strauss & Corbin, 1990; 1998) is the process by which thematic codes are combined to draw together similar concepts, or separated to provide greater granularity. Selective coding is used when it has been established which axial codes are fundamental to answering the research questions. These are the core variables and the continuing coding process can then focus on them, with other codes relegated to secondary importance. Any further coding of new text uses the selective codes, and this is called theoretical sampling (Glaser, 1998). As there was no planned process of saturation, selective coding did not take place until all the interview transcriptions were coded.

Saturation occurs when there are no new categories or themes emerging and further analysis of new data is deemed unnecessary (Strauss & Corbin, 1998). As finding participants for the study was expected to be problematic, I had always intended to code all available interview data irrespective of any potential saturation. In actuality data saturation did not occur as the dyscalculic students were heterogeneous in terms of courses and life experiences, and always introduced new individualised codes.

The codes that are deemed to be most pertinent are referred to as theoretical codes, and woven into related concepts to form a theory that attempts to explain the behaviour of the participants and answer the research questions. As saturation was not used to
delimit the theoretical codes, the frequency and distribution of codes was examined to explore which topics were most relevant to the dyscalculic students.

Strauss and Corbin (1990) described the concept of ‘theoretical sensitivity’ where the researcher’s experience and familiarity with the data affect the potential to extract pertinent information to lead to a conceptually dense and well integrated theory.

6.6 Summary

This chapter discussed the methodology employed in my research which takes an interpretive grounded theory approach. The themes most relevant to the participants were allowed to emerge from data analysis, rather than from a pre-prescribed focus on any particular aspect of dyscalculia. As my chosen data collection method was a semi-structured interview, I recognise that some topics of discussion are pre-conceived, but this was necessary to ensure that the wider domain of conversation was consistent between participants. The process of analysis, by means of coding frequency, is designed to provide a subjective interpretation of the aspects of being dyscalculic which the participants felt were most relevant to their academic and everyday lives.
Chapter 7 - Implementation

7 Implementation

7.1 Introduction

This chapter describes the implementation of the research methodology in my study. Firstly, I discuss the participant selection process, which was a major risk for the research in terms of locating and recruiting sufficient numbers of dyscalculic students to make the research viable. I also give a rationale for the exclusion of three participants. I then describe the implementation of the data collection and analysis process, as outlined in chapter 6, which includes the coding of themes and categorisation of dyscalculic profiles. Finally I discuss the secondary data sources, which were the support sessions with two students, one dyscalculic and one dyslexic, and their role in the study.

7.2 Participant selection

There was a risk of under-recruitment for this study due to the low number of identified dyscalculic students in HE, and their wide geographical distribution. A survey (discussed in appendix I), with a response rate of 24% of HE institutions in the UK, found the modal number of dyscalculic students per institution to be three. This would predict the size of the national population of dyscalculic students in HE to be approximately 400. The small size of this population and geographical spread, together with budgetary limitations on travel presented significant barriers to recruitment.

I considered a target sample size of between twelve and twenty participants to be a realistic goal given the time available to find, interview and analyse the data from each student. This sample size target was also large enough to provide the required depth of data and provide a likely diversity of participants in terms of gender, age, background and chosen course. The inclusion criteria were that participants must be current or recent students of higher education, aged 18 or over, and have been officially identified as dyscalculic by an educational psychologist or recognised assessor. I considered dyscalculia identification to be the biggest risk to my study, as I was relying on the validity of a neurodiversity assessment process that is known to be problematic (Butterworth, 2002; Trott, 2007). However beyond re-screening and re-assessing, which was prohibited by time and financial cost, there was no other option. I did however reserve the right to exclude participants if I felt that the identification was doubtful, on condition that I could substantiate my reasons, which did occur with one student (see section 7.4.1).
The primary mode of contact was an email to the several JISCmail groups (JISCMail, 2012), including SpLD, Dis-Forum, ADSHE and DDIG, which are online forums observed to be well-frequented by HE learning support practitioners. The email explained the purpose of the study, and requested a referral to any suitable candidates. The process was for the practitioner to contact the student and pass on my details. The student would then contact me if they wished to take part. Additional strategies included the use of my supervisor's own informal network of contacts within other HEIs to petition learning support practitioners directly, and promotion of my study at relevant conferences and regional group meetings. As no budget was available for travel costs, the search focussed mostly on regional institutions within the Midlands. Despite five participants being recruited locally, progress was slow, but the minimum number of dyscalculic students was achieved despite three being excluded at a late stage for reasons of logistics or criteria shortfall (see section 7.4). Where a participant had been recommended by a learning support tutor, initial contact was undertaken by that tutor, who was kept informed of progress during the research process.

Immediately prior to the recruitment deadline, it became apparent that there were two possible areas of the dyscalculic student population that may have not been adequately represented: male students and students studying subjects allied to medicine. Although no evidence was identified within a literature search to suggest that gender is a predisposing factor for dyscalculia, it may be possible that gender is a factor in how dyscalculic students create coping strategies or form identities. My sample contained significantly more women than men. I theorised that this could be a statistical anomaly due to the small sample size, or because female dyscalculic students are more likely to enter higher education, or possibly as a result of the female gender being more willing to participate in a study of this type although I have no data to support this conjecture. ‘Subjects allied to medicine’ have been shown to be a subject area that many dyscalculic students choose to study (see appendix I). This has highlighted the issue of fitness to practise (see chapter 12) within the healthcare sector, raising awareness which has been reflected in recent papers discussing the issues around dyscalculic nurses and other practitioners practising in a high risk environment involving mathematical skills (Kirk, 2012). I felt it was important therefore, to try and consider issues around 'fitness to practise' within my study, and was concerned that my data would not facilitate that as my sample contained only one mature medical student and student teacher (Education being another sector with formalised 'fitness to practise' regulation). The lack of forthcoming participants from that sector was initially a surprise, given the data from the Drew and Trott survey (see appendix I) alongside anecdotal evidence.
<table>
<thead>
<tr>
<th>Alias</th>
<th>Age</th>
<th>Type of student</th>
<th>HEI</th>
<th>Subject</th>
<th>Neurodiversity</th>
<th>Involvement</th>
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<tbody>
<tr>
<td>Alison</td>
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<td>Undergraduate</td>
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<td>Interview method only</td>
</tr>
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<td>Undergraduate</td>
<td>HEI 01 (Midlands)</td>
<td>Media textiles</td>
<td>Co-occurrence of dyscalculia with dyslexia &amp; visual stress</td>
<td>Interview method only</td>
</tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Deborah</td>
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<td>2nd degree undergraduate</td>
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<td>Interview method only</td>
</tr>
<tr>
<td>Ellen</td>
<td>20s</td>
<td>Undergraduate</td>
<td>HEI 02 (Midlands)</td>
<td>Geology</td>
<td>Co-occurrence of dyscalculia with dyslexia &amp; visual stress</td>
<td>Interview method only</td>
</tr>
<tr>
<td>Fiona</td>
<td>40s</td>
<td>Foundation to HE</td>
<td>HEI 03 (Midlands)</td>
<td>Wildlife &amp; countryside management</td>
<td>Dyscalculic-only</td>
<td>Both interview and tutor method</td>
</tr>
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<td>Gemma</td>
<td>20s</td>
<td>Undergraduate</td>
<td>HEI 04 (Midlands)</td>
<td>Computer studies</td>
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<td>Interview method only</td>
</tr>
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<td>Postgraduate PGCE</td>
<td>HEI 05 (South)</td>
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<td>Interview method only</td>
</tr>
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<td>Construction</td>
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<td>Tutor method only</td>
</tr>
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<td>Julie</td>
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<td>Postgraduate MA</td>
<td>HEI 02 (Midlands)</td>
<td>History</td>
<td>Dyscalculic-only &amp; visual stress</td>
<td>Interview method only</td>
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### Table 7 – List of participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Age</th>
<th>Status</th>
<th>HEI Code (Region)</th>
<th>Field of Study</th>
<th>Additional Conditions</th>
<th>Method of Study</th>
</tr>
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<td>Excluded from study</td>
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<td></td>
<td></td>
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<tr>
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<td>HEI 07 (Midlands)</td>
<td>Criminology</td>
<td>Dyscalculic-only &amp; possible visual stress</td>
<td>Interview method only</td>
</tr>
<tr>
<td>Maggie</td>
<td>20s</td>
<td>Foundation to HE</td>
<td>HEI 05 (Midlands)</td>
<td>Science</td>
<td>Co-occurrence of dyscalculia with dyslexia</td>
<td>Interview method only</td>
</tr>
<tr>
<td>Nancy</td>
<td>30s</td>
<td>Postgraduate PhD</td>
<td>HEI 08 (North)</td>
<td>Fine art</td>
<td>Co-occurrence of dyscalculia with dyspraxia</td>
<td>Interview method only</td>
</tr>
<tr>
<td>Olivia</td>
<td>20s</td>
<td>Graduate</td>
<td>HEI 01 (Midlands)</td>
<td>Management science</td>
<td>Dyscalculic-only</td>
<td>Interview method only</td>
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<tr>
<td>Paulette</td>
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<tr>
<td>Quentin</td>
<td>30s</td>
<td>Postgraduate MA</td>
<td>HEI 09 (Scotland)</td>
<td>Psychology</td>
<td>Dyscalculic-only</td>
<td>Interview method only</td>
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<td>Rebecca</td>
<td>20s</td>
<td>Undergraduate</td>
<td>HEI 10 (Scotland)</td>
<td>Nursing</td>
<td>Co-occurrence of dyscalculia with dyspraxia</td>
<td>Interview method only</td>
</tr>
</tbody>
</table>

**Key:**
- Participants in interview method only
- Participants in tutor method only
- Participants in both interview and tutor method
- Potential participants rejected from the study

**Table 7 – List of participants**
On reflection it may be that dyscalculic health practitioners avoid disclosure of their difficulties, choosing not to come forward for fear of risking their careers. I therefore attempted to focus one further recruitment strategy on locating a student nurse or midwife, for whom fitness to practise issues would be relevant.

A further email was sent to the JISCmail forums, and a presentation was given to a conference specialising in mathematical difficulties encountered by nurses. This led to contact from a newly qualified dyscalculic nurse in Scotland, who was keen to take part in the study and share her experiences. Departmental funding was sourced for travel expenses, and the excursion also permitted an additional interview of a male Scottish participant, who had initially been omitted due to travel costs. The final number of participants recruited was 14, not counting the three exclusions, and anonymised details can be found in table 7. Full participant biographies can be found in appendix F.

All but two of the participants were current HE students. The remaining two participants were a recent graduate and a current employee who had put a postgraduate course on hold for financial reasons.

### 7.3 Participant biographies

Full participant biographies including timeline diagrams can be found in appendix F. These show a summary of the narrative of each participant collected from interview, and a visual representation of the gaps between significant events in their personal histories.

### 7.4 Rationale for student exclusions

Three students who were initially selected to be participants were rejected from the study at various stages. The reasons for their exclusion are given below.

#### 7.4.1 Christophe

Christophe was an international student studying for a Masters degree in finance. He was also an employee within the banking sector in Southern Europe. He arrived in Britain with an identification of dyscalculia, dyslexia and dysgraphia from his home country of Greece although the report was considerably less detailed than the British equivalent. He had received one-to-one support during his present course, where he had asked for help with calculus. At interview, it became clear that his mathematics education had not included calculus, which is part of the British A-level syllabus in mathematics. He had a sound understanding of arithmetic concepts, which is required for working in a bank. He had some difficulties with mental arithmetic, but was able to perform tasks on paper
with little difficulty. In his interview there was no evidence of dyscalculia. In discussion with Christophe’s tutor it became clear that Christophe most likely had a neurodiversity of dyslexia with mathematical difficulties which had been exacerbated by an educational issue and the mismatch of curricula. I therefore decided that there was sufficient evidence to cast doubt on Christophe’s identification and warrant his data being excluded.

7.4.2 Karen

Karen was scheduled to take part, but an interview never took place. Karen had recently been involved in a road traffic accident, and was housebound and unable to comfortably meet in a neutral venue. Although she was happy for the interview to take place at her home, this would have contravened the terms of the ethics approval. The interview was initially postponed, but due to the deadline for completing data collection, the interview was eventually cancelled.

7.4.3 Paulette

The exclusion of Paulette’s data was a difficult decision. She was the only student who was interviewed twice, initially as part of a pilot process, and then as a follow-up after completing a statistical assignment within her course in Ergonomics. Paulette was identified with dyscalculia, and observational evidence from her tutor supported this identification. However, Paulette did not discuss her mathematical difficulties, and instead described a successful academic career where mathematics had not been a major concern. This could have been important data to the study, showing how a dyscalculic student had overcome mathematical difficulties. Her narrative, however, was in contrast to the account of her tutor, making the data more complicated to interpret. Her story was not about overcoming difficulties, but rather about not having them at all. As the pilot interview had appeared to remain at a superficial level, I decided to interview her a second time after she had recently completed a mathematics project, to see whether there was a change in her views on dyscalculia. The second interview was similar to the first, and her account of the events of working with her tutor was in complete contrast to the account given by the tutor. It appeared on the surface that for some reason, Paulette was unable to discuss her dyscalculia openly. As she was a student known by my supervisor, it may be that she felt unable to refuse participation even though the voluntary nature of the study was made explicit. Although a study of Paulette’s response would make an interesting case study regarding her ‘denial’ of difficulties, the value of the data remained questionable. I therefore reluctantly decided to exclude her as a participant.
7.5 Data analysis

7.5.1 Coding implementation

Each interview was audio-recorded with the written consent of the participant then transcribed either personally or using a third party transcription service. Each transcription was checked for accuracy, and annotated by myself from field notes to signify pauses, body language and inflections. The transcriptions were also anonymised at this point, removing all names of people, educational institutions and geographical locations. The transcriptions were then loaded into Atlas TI (2015) qualitative analysis software. I chose to make the unit of analysis an entire paragraph, which could include the researcher’s question if necessary. Each transcription was then coded at least twice with a content code and a timeline code. A content code described what was happening, either a physical event or emotion associated with that event. A timeline code marked the point in a participant’s story at which the content occurred, for example during childhood, in higher education, or in the workplace. Content codes are the thematic codes by which narratives can be explored to find commonalities and contrasts (see section 6.5.3). Timeline codes provided supplementary information useful to match the participant’s stories by life event. Memos were used to describe each code and my rules of application. In some instances of code application I added a note to capture my thought processes at the time.

Using the principles of grounded theory (see section 6.2), codes were not pre-determined, but allowed to emerge from the text. After two transcriptions were fully coded, the codes were examined to see how they could be categorised. This process was purely for organisation and to provide structure, and not due to any pre-conceived ideas of how the codes should appear. After each further transcription coding process, the new codes were compared to existing codes. Codes that were found to encompass too many differing concepts were subdivided by creating a hierarchy of codes (see appendix P). For example the theme of mathematics included a subtheme of shape and space, which in turn included subthemes of trigonometry, area, 3d etc. Where identical or similar themes had been coded differently, the codes were merged to form a new code. When the coding process was complete, over 400 codes had been created.

As finding participants was difficult, the coding process did not cease due to saturation, but rather when all participant interviews had been coded. Saturation may not be possible as the analysis of each interview was creating new codes due to the unique personal or course-related experiences of the participant that could not be shared by the rest of the sample. For example, a non-mature student with a similar academic profile to
previous participants would create a number in the region of ten new codes, whereas Rebecca, the nurse, and one of the last interviews to be transcribed, created over fifty new codes as she was the only current nurse in my sample.

### 7.5.2 Resultant codes

When the coding process was complete, each code was allocated to a different category (see table 8). The codes were reviewed once the final transcription had been coded. The frequency and distribution of codes was then examined to explore which topics were most relevant to the participants. VENN style diagrams were created to examine how the codes interrelated between varying groups of participants (see appendix Q). The number of relevant codes was still too high to allow the study to be manageable, so I was forced to reduce the scope of the study and rigidly enforce modified research questions that reinforced the emphasis on higher education (see section 1.3). This resulted in the exclusion of childhood, workplace and everyday life narrative data that seemed not to relate directly to the higher education experience.

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coping</td>
<td>Assistance</td>
<td>Friends or family as part of a coping strategy</td>
</tr>
<tr>
<td></td>
<td>Effort</td>
<td>Effort as a means to success</td>
</tr>
<tr>
<td></td>
<td>Everyday</td>
<td>Coping strategies for everyday tasks</td>
</tr>
<tr>
<td></td>
<td>Memory</td>
<td>Coping strategies to improve memory</td>
</tr>
<tr>
<td></td>
<td>Numeracy</td>
<td>Coping strategies for numerical operations</td>
</tr>
<tr>
<td></td>
<td>Study</td>
<td>Coping strategies to help with studying</td>
</tr>
<tr>
<td>Education</td>
<td>Environment</td>
<td>Environmental and practical factors due to the physical and cultural nature of the institution.</td>
</tr>
<tr>
<td></td>
<td>Learning</td>
<td>How each participant wants to learn or experiences on how they were made to learn.</td>
</tr>
<tr>
<td></td>
<td>Assessment</td>
<td>Assessment during education</td>
</tr>
<tr>
<td>Emotions</td>
<td>Education</td>
<td>A strong emotional reaction to education</td>
</tr>
<tr>
<td></td>
<td>Mathematics</td>
<td>A strong emotional reaction to mathematics</td>
</tr>
<tr>
<td></td>
<td>Neurodiversity</td>
<td>A strong emotional reaction to due a neurodiversity.</td>
</tr>
<tr>
<td></td>
<td>Work</td>
<td>A strong emotional reaction to work or placement</td>
</tr>
</tbody>
</table>
### Table 8 – List of code categories

With over 400 codes, it became clear that the scope of the study would have to be reduced to make the study manageable. Therefore the study and the research questions were modified to reinforce the emphasis on HE, and to exclude childhood, work or everyday life narrative that wasn’t directly related to HE experience. This led to the
exclusion of a large amount of data, specifically with regard to childhood experiences. The participants were particularly keen to talk about the impact of childhood experiences on their lives, and I hope that this data could be used to inform a different study in the future.

All the high frequency codes were experienced by all fourteen participants. A cut-off was chosen at fifty occurrences, which led to 42 codes (see table 9). Timeline codes were excluded. There was also a code created called meta-cognition, which was designed to mark each occurrence where the participant showed an understanding of how their dyscalculia affected their lives. This code occurred almost 500 times, and was discarded as being so common that the purpose for the coding had been ill-considered. But on reflection, this code suggested that participants were perceptive with regards to their own mathematical difficulties and were able to strongly articulate their understanding of dyscalculia. This highlighted the importance of adult-based research in contrast to studies involving only children who may not be as self-aware due to fewer life experiences.

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Code</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotions</td>
<td>Mathematics</td>
<td>Performance</td>
<td>232</td>
</tr>
<tr>
<td>Emotions</td>
<td>Mathematics</td>
<td>Mathematics as a subject</td>
<td>198</td>
</tr>
<tr>
<td>Emotions</td>
<td>Education</td>
<td>Support</td>
<td>158</td>
</tr>
<tr>
<td>Coping</td>
<td>Effort</td>
<td>Avoidance</td>
<td>148</td>
</tr>
<tr>
<td>Emotions</td>
<td>Mathematics</td>
<td>Learning</td>
<td>139</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Other</td>
<td>Mathematical anxiety</td>
<td>129</td>
</tr>
<tr>
<td>Emotions</td>
<td>Neurodiversity</td>
<td>Dyscalculia</td>
<td>120</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Other</td>
<td>Long term memory</td>
<td>104</td>
</tr>
<tr>
<td>Education</td>
<td>Assessment</td>
<td>GCSE</td>
<td>102</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Understanding</td>
<td>Number conceptualisation</td>
<td>99</td>
</tr>
<tr>
<td>Support</td>
<td>HE</td>
<td>SpLD assessment</td>
<td>99</td>
</tr>
<tr>
<td>Support</td>
<td>HE</td>
<td>Tutors</td>
<td>97</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Statistics</td>
<td>Graphics</td>
<td>89</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Other</td>
<td>Identification</td>
<td>87</td>
</tr>
<tr>
<td>Emotions</td>
<td>People</td>
<td>Peer comparison</td>
<td>84</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Other</td>
<td>Working memory</td>
<td>82</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Other</td>
<td>Dyslexia</td>
<td>81</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------</td>
<td>------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Emotions</td>
<td>Education</td>
<td>HE</td>
<td>76</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Real world</td>
<td>Money</td>
<td>75</td>
</tr>
<tr>
<td>Coping</td>
<td>Effort</td>
<td>Hard work</td>
<td>72</td>
</tr>
<tr>
<td>Emotions</td>
<td>Neurodiversity</td>
<td>Coping mechanisms</td>
<td>72</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Real world</td>
<td>Time</td>
<td>72</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Facets</td>
<td>Slow processing</td>
<td>69</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Facets</td>
<td>Spatial awareness</td>
<td>65</td>
</tr>
<tr>
<td>Coping</td>
<td>Assistance</td>
<td>External help</td>
<td>62</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Numeracy</td>
<td>General</td>
<td>62</td>
</tr>
<tr>
<td>Emotions</td>
<td>Neurodiversity</td>
<td>Intelligence</td>
<td>60</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Understanding</td>
<td>Awareness</td>
<td>60</td>
</tr>
<tr>
<td>Support</td>
<td>HE</td>
<td>One to one tuition</td>
<td>60</td>
</tr>
<tr>
<td>Life</td>
<td>N/A</td>
<td>Time management</td>
<td>59</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Representations</td>
<td>Reading and writing numbers</td>
<td>59</td>
</tr>
<tr>
<td>Neurodiversity</td>
<td>Facets</td>
<td>Numerosity</td>
<td>57</td>
</tr>
<tr>
<td>Emotions</td>
<td>Education</td>
<td>Assessment</td>
<td>54</td>
</tr>
<tr>
<td>Emotions</td>
<td>Work</td>
<td>Career</td>
<td>54</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Numeracy</td>
<td>Fractions</td>
<td>54</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Real world</td>
<td>Mental arithmetic</td>
<td>53</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Statistics</td>
<td>General</td>
<td>52</td>
</tr>
<tr>
<td>Coping</td>
<td>Study</td>
<td>Organisation</td>
<td>51</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Statistics</td>
<td>Advanced statistics</td>
<td>51</td>
</tr>
<tr>
<td>Education</td>
<td>Assessment</td>
<td>Exams</td>
<td>50</td>
</tr>
<tr>
<td>Emotions</td>
<td>People</td>
<td>Lecturers</td>
<td>50</td>
</tr>
<tr>
<td>Emotions</td>
<td>Work</td>
<td>Fitness to practise</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 9 – Codes with frequency greater than 50 occurrences
7.5.3 Extraction of themes

Once the codes had been chosen using the criteria of frequency, they were organised in terms of relevance to the four research questions. The text corresponding to the codes was then used to form theories about the nature of dyscalculia and the issues most relevant to the participants. The similarities and differences between the participants were then explored to see whether they could be explained by varying characteristics of dyscalculia, which led to the creation of several profiles of dyscalculia which are discussed in the next section. To create an audit trail between the codes and ideas, a matrix form was created for each section of the findings to link the participants’ responses to each idea, where applicable. A sample of some of these matrix forms can be found in appendix R. The code matrix forms also show the content codes that were initially used to form the specific theory, but also other codes that are then drawn upon to provide further depth.

7.6 Categories of dyscalculia

Current definitions that rely on a discrepancy model conceptualise dyscalculia as a spectrum of mathematical difficulty (see section 3.3.1.4). Other models, such as that suggested by Butterworth (see section 3.3.1.2), suggest that dyscalculia is not a spectrum of mathematics difficulty, but a smaller set of more fundamental specific difficulties. The participants in my study showed varying levels of mathematical ability, and not all participants struggled with the same mathematical concepts. An identification of dyscalculia is currently based upon the discrepancy model, it was logical to predict that the participants in my study would demonstrate a spectrum of difficulty. This is compatible with the socio-cultural perspective that each participant has differing individualised needs that are a function of their place in society.

Throughout the data analysis, I noticed trends in the dyscalculia-related characteristics and emotional reactions amongst the participants. These trends emerged from the data as possible explanations for why participants in the study demonstrated differing characteristics in particular scenarios. From this, I was able to categorise several groups of dyscalculic student within the sample, which are hereafter referred to as ‘categorisations of dyscalculia’ or the ‘Grounded’ model (see table 10).

As some of these categories overlap, I have created three bands of groups which I refer to as A, B and C. The groups in band A can be considered as subsets of the groups in band B and C, which is shown in figures 16 and 17.
In chapters eight, nine and ten, the groups of dyscalculia profiles provide a framework within which the relationship between the participants and each theme is explored. In chapter eleven I explore the band A categories in relation to the idea of identity and how they may relate to other research on neurodiverse profiles.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Band A</th>
<th>Code</th>
<th>Band B</th>
<th>Code</th>
<th>Band C</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linda</td>
<td>Dyscalculia with numerosity issues</td>
<td>DWN</td>
<td>Severely dyscalculic</td>
<td>SDY</td>
<td>Dyscalculia only</td>
<td>DYO</td>
</tr>
<tr>
<td>Maggie</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nancy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiona</td>
<td>Dyscalculia without numerosity issues</td>
<td>DWO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rebecca</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deborah</td>
<td>High achievers</td>
<td>H Ach</td>
<td>Moderately dyscalculic</td>
<td>MDY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gemma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Julie</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heather</td>
<td>Highly anxious</td>
<td>H Anx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quentin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alison</td>
<td>Co-occurrence of dyscalculia and dyslexia</td>
<td>CDD</td>
<td>Co-occurrence of dyscalculia and dyslexia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bradley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 10 – List of categories of dyscalculia for the Grounded model**

**Figure 16 – Relationship between dyscalculic categories in bands A and B**
7.6.1 Band A categories

Band A is the most granulated division of my sample and divides the participants into five categories based upon their most defining characteristics.

7.6.1.1 Dyscalculia with numerosity issues

This category is characterised by participants who showed evidence in their data of the fundamental numerosity and subitising issues associated with the Butterworth model of dyscalculia (see section 3.8.1). Participants in this group were the most severely dyscalculic in the sample.

7.6.1.2 Dyscalculia without numerosity issues

This category describes participants who had been identified as dyscalculic due to the medical discrepancy model (see section 2.3.2). They had severe mathematical weaknesses, but did not show evidence of the most fundamental issues with numerosity.

7.6.1.3 High achievers

This category contains high achieving participants who had succeeded academically. This may be surprising given their dyscalculia. They included mature students who had already enjoyed a successful career, and students who were enrolled on courses that may be considered too mathematically demanding for other dyscalculic students by their parents, peers or teachers. They had been identified using the discrepancy model (see section 3.3.1.4), but their mathematical ability was considered poor only in contrast to their exceptionally high general intelligence. This is not to say that those in other
categories are not high achievers, but this category describes participants who from the outside do not appear to have been affected by their dyscalculia.

### 7.6.1.4 Highly anxious

This category contains participants who displayed high levels of both mathematics-related and general anxiety. Their level of anxiety was in excess of the mathematical anxiety expected of dyscalculic individuals. This anxiety pervaded all areas of their life, and therefore makes an identification of dyscalculia difficult as many of the observed difficulties may be anxiety-related rather than caused by dyscalculia.

### 7.6.1.5 Co-occurrence of dyscalculia and dyslexia

This category refers to participants who were also identified as being dyslexic, but who were able to use positive characteristics of their dyslexia to develop strategies to cope with their dyscalculia. This does not necessarily mean that all participants who were also dyslexic were aligned with this group, if they described characteristics associated more with another group.

<table>
<thead>
<tr>
<th>Band A category</th>
<th>Participant</th>
<th>Reason for alignment</th>
<th>Possible alternative groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyscalculia with numerosity issues (DWN)</td>
<td>Linda</td>
<td>Demonstrated fundamental conceptual difficulties, such as comparing prices of purchased items (numerosity), associating numbers with patterns (subitising) and counting without missing sections.</td>
<td>None</td>
</tr>
<tr>
<td>Maggie</td>
<td>Exhibited severe difficulties with numerosity, such as standardisation of units of measure.</td>
<td>Was also dyslexic so could be a member of the CDD group.</td>
<td></td>
</tr>
<tr>
<td>Nancy</td>
<td>Struggled with numerosity, and could only judge distances by her husband’s height of six feet.</td>
<td>Although not dyslexic, her strong artistic skills gave her similar characteristics to dyslexic participants in the CDD group.</td>
<td></td>
</tr>
<tr>
<td>Dyscalculia without numerosity issues (DWO)</td>
<td>Fiona</td>
<td>Although Fiona described significant mathematical difficulties (supported by her EP report), there was less data to suggest her difficulties were as fundamental as some of the other</td>
<td>Fiona did have some subitising issues, but without strong evidence of numerosity difficulties I chose not to include her in the DWN group.</td>
</tr>
</tbody>
</table>
participants. Fiona also had a high level of mathematical anxiety, but I felt it was not her most defining characteristic and therefore excluded the *HAnx* group.

<table>
<thead>
<tr>
<th></th>
<th>Olivia</th>
<th>Olivia described severe mathematical difficulty but without the fundamental numerosity issues.</th>
<th>Although not dyslexic, Olivia had developed strong coping strategies and was very aware of her academic strengths.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rebecca</td>
<td>Although Rebecca described severe mathematical difficulty, she did not relate any numerosity issues.</td>
<td>Rebecca described fundamental difficulties with real numbers which may have made her a candidate for the <em>DWN</em> group.</td>
</tr>
</tbody>
</table>

**Highly anxious (HAnx)**

<table>
<thead>
<tr>
<th></th>
<th>Heather</th>
<th>Used the language of stress continually during her interview.</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quentin</td>
<td>Used the language of stress continually during his interview.</td>
<td>None</td>
</tr>
</tbody>
</table>

**High achievers (HAh)**

<table>
<thead>
<tr>
<th></th>
<th>Deborah</th>
<th>A mature student who had a successful career in nursing and midwifery and was now studying medicine.</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gemma</td>
<td>Enrolled in a hard science degree course that would have required a higher level of mathematics than expected for a dyscalculic student.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Julie</td>
<td>A mature student who had a successful career as a lawyer.</td>
<td>None</td>
</tr>
</tbody>
</table>

**Co-occurrence of dyscalculia and dyslexia (CDD)**

<table>
<thead>
<tr>
<th></th>
<th>Alison</th>
<th>Strongly identified with her strengths due to her dyslexia.</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bradley</td>
<td>As well as being dyslexic, was also artistic and had strong visual skills.</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Ellen</td>
<td>Her dyslexia was able to facilitate a better grasp of mathematics through kinaesthetic learning, such as using physical money.</td>
<td>As Ellen’s dyslexic tendencies were not quite as pronounced as some others, I considered aligning her with the <em>DWO</em> group.</td>
</tr>
</tbody>
</table>

| **Table 11 – Participant alignment to category of dyscalculia** |
Although co-occurrences of other neurodiversities such as dyspraxia did occur in the sample population, I did not feel that the prevalence within the sample was high enough, or the relevant characteristics pronounced enough, to constitute a separate categorisation. These other factors are, however, mentioned at times within the thesis when they appear to have relevance to the findings.

Each participant was assigned to a particular band A category based upon my interpretation of their interview data. Some participants had a very strong narrative dominated by a single theme that was only applicable to one category. Other participants described characteristics that could represent more than one group. For example, a participant could be both highly anxious and have dyslexia. I considered continuing my analysis whilst incorporating the overlap, but decided this was not feasible due to the complexity of considering participants in multiple groups. I therefore chose to align each participant with a single group in order to keep the analysis as straightforward as possible. I recognise, however, that analysing multiple alignments could give more depth. Table 11 shows a table of participants aligned to band A categories.

I have given the rationale for the alignment, but also documented where other alignments could have been considered. On occasion, I do consider a participant’s characteristics that are identified with another group where this can potentially inform the discussion. For example, Maggie was dyslexic, and at times showed some of the characteristics of the co-occurrence of dyscalculia and dyslexia (CDD) group. However, her numerosity issues affected her studies and everyday life far more noticeably than her dyslexia so she was primarily aligned with the DWN group and her dyslexia is discussed where relevant.

### 7.6.2 Band B categories

Band B is a division of the participants by their level of mathematical difficulty, and consists of two groups. I noticed that participants belonging to the dyscalculia with numerosity issues and dyscalculia without numerosity issues groups had significantly more mathematical difficulties than the remaining participants. I have therefore created two groups, severely dyscalculic and moderately dyscalculic to describe situations where the severity of mathematical difficulty was most relevant.

### 7.6.3 Band C categories

Band C incorporates the group dyscalculia only to help compare the students with a co-occurrence of dyscalculia and dyslexia with the rest of the sample. The co-occurrence of dyscalculia and dyslexia in band C is the same group as defined in band A.
### 7.6.4 Non-dyscalculic groups

There were two further groups of interest that emerged from the data as explanations for some of the findings, but were not related to characteristics of dyscalculia.

#### 7.6.4.1 Fitness to practise group

This group describes participants who have chosen a career path that is associated with formalised ‘fitness to practise’ regulation. Whilst a certain level of ‘fitness for purpose’ is expected in any profession, roles involving the public or children are subject to extra regulation for example the Nursing and Midwifery Council (NMC) for nurses and midwives, General Medical Council (GMC) for doctors and Department of Education for teachers (see section 12.4). From a dyscalculic perspective, fitness to practise covers mathematical competency in those settings. Within this study, this concerned three participants, Deborah, Heather and Rebecca who were studying medicine, nursing and teaching respectively.

#### 7.6.4.2 Visual stress group

This group contains participants who have an identification of visual stress and includes Bradley, Ellen and Julie. Although not a feature of dyscalculia, it appeared to affect some of the findings (see section 4.5).

### 7.7 Secondary data

#### 7.7.1 Support sessions

As well as the interview data which was my primary data, I used reflective accounts of tuition sessions to provide another source of information. As described in section 6.5.1.2, this is not a deep analysis, but a background secondary source of data for me to draw upon where possible to back up the claims of the participants during interview. This data was not coded. The support sessions were arranged with two participants, Fiona and Ian. The purpose of these sessions was to help me better understand the differences between dyscalculia and dyslexia with mathematical difficulties, through personal experience. My reflections on supporting the two students can be found in appendix K.

### 7.8 Summary

The thematic analysis described in this chapter has highlighted the areas of academic and everyday life that are most important to the participants with respect to their
experiences of being dyscalculic. These coded themes have then been compared to the research questions to create a framework for reporting my interpretation of the views of the participants.

In exploring the differences between the participants, I was able to deduce categories of characteristics that could be consolidated into five separate profiles of dyscalculia. Some of these were also combined to create eight profiles in total. With just a few exceptions the findings could be mapped to these groups.

The next four chapters describe the findings of the analysis, and correspond to each of the four research questions.
Chapter 8 – Experiences leading to identification of dyscalculia

8 Experiences leading to identification of dyscalculia

8.1 Introduction

This chapter addresses the first research question:

What are the experiences of dyscalculic students in HE that lead to identification of dyscalculia?

It explores the various participant journeys up to and including the identification process. The initial section explores whether achieving a pass in GCSE mathematics had affected the academic careers of the participants, and examines their chosen routes to entering HE. It goes on to highlight the effect of the relationship with teachers and parents on the decision to apply for HE as well as the participants’ thoughts about their potential career options as a dyscalculic individual in the workplace.

The next section explores subject choices of dyscalculic students in HE. My analysis has shown that lack of awareness of mathematical content as described by Trott (2003) was a contributing factor, but was only one of four separate factors affecting decision-making employed by participants (see table 13).

This third section discusses the anxiety that is frequently faced by dyscalculic students when they encounter mathematics. A full literature review of mathematical anxiety (MA) can be found in section 4.4.1. As all the participants in the study described behaviour consistent with extreme mathematical anxiety, it is unsurprising that a fear of mathematics was found to be a major consideration in dyscalculic students’ academic choices. I have chosen to use the term mathematical anxiety loosely to cover any mathematics-based event that caused the student stress. For example when a student suffered a panic attack before taking a mathematics exam, or when buying goods at a till, I considered the episode as a MA event. I also separate statistical anxiety from mathematical anxiety as some researchers suggest this could be a different phenomenon (see section 4.4.3). In order to study MA in its own right, the narratives have been searched for incidences where mathematics had caused what Sheffield (2006) described as either a psychological, physical or biological event (see section 4.4.1), in a situation that would most likely not be deemed stressful to a neurotypical student. These occurrences have been classed as mathematical anxiety relating to numeracy (see section 8.4.1) and are discussed separately from statistical anxiety (see section 8.4.2) or wider stress situations that have their roots in mathematics but may be symptomatic of wider anxiety issues (see section 8.4.3).
An important theme to emerge was the participants’ vivid descriptions of a ‘mental block’, where they experienced a mental inhibition on encountering numbers and symbols. On further investigation this appeared to be the participants’ own descriptions of working memory inhibition due to MA (see section 8.4.4). Finally the section looks at the coping mechanisms for dealing with mathematical anxiety, which was predominantly a strategy of avoidance.

The final section examines the participants’ reactions to being identified with dyscalculia and their experiences of the identification process.

### 8.2 Prior experiences leading to application to higher education

This section explores the participants reasons for entering HE and the factors that were part of their decision making process.

#### 8.2.1 GCSE mathematics and access to HE

Ten of the fourteen participants failed to pass GCSE mathematics or equivalent whilst at school (see table 12). This included all of the *severely dyscalculic (SDY)* participants apart from Olivia, who had developed some early coping strategies through organisation and presentation, and had described herself as very fortunate to pass. She had broken a limb in a fall on the morning of her exam, and was allowed to be assessed on only two pieces of work, which gave greater weighting to her coursework, which had gained top marks due to her excellent presentation skills and hard work.

Three of the participants chose to re-take GCSE mathematics as mature students in order to continue their studies, and were able to pass having found invaluable support from family or friends.

> *They don’t understand what I struggle with and how I struggle with it. A friend helped me with my GCSE, my ‘O’ level, but he was a special needs tutor at the school I’m working at and he actually has an interest in dyscalculia.* (Fiona)

Seven of the students were able to pursue tertiary education without a mathematics qualification either by taking an access course to HE or by choosing degrees that did not require a mathematics GCSE (see sections 8.2.1 & 8.3). This included all the participants in the *dyscalculia with numerosity issues (DWN)* group. At the start of my research I had presumed that dyscalulcic students who successfully reach HE had somehow managed to achieve a grade C in GCSE mathematics at school, but the data suggested this was unusual. Most of the participants in the study had entered HE using well established alternative routes (see table 12). This demonstrated that failure to gain a GCSE grade C
in mathematics was not a barrier to access HE for the students in this study. It is notable that the participants who I categorised as *high achievers (HAch)* did not all attain GCSE mathematics at school, with Gemma being the only student in this category who attained an A-C grade first time. This suggests that initial GCSE mathematics success is not an indicator of whether a dyscalculic student can attain academic or career success.

<table>
<thead>
<tr>
<th>Participants</th>
<th>GCSE or equiv.</th>
<th>Route to HE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gemma</td>
<td>B</td>
<td>Passed A levels and then on to HE.</td>
</tr>
<tr>
<td>Olivia</td>
<td>B</td>
<td>Passed A levels and then on to HE.</td>
</tr>
<tr>
<td>Alison</td>
<td>C</td>
<td>Passed A levels and then on to HE.</td>
</tr>
<tr>
<td>Ellen</td>
<td>C</td>
<td>Passed A levels and then on to HE.</td>
</tr>
<tr>
<td>Bradley</td>
<td>D (two attempts)</td>
<td>Passed A levels and then did a foundation course in FE.</td>
</tr>
<tr>
<td>Deborah</td>
<td>D (achieved B in re-sit during HE as mature student)</td>
<td>Passed A levels and went to FE to do BTEC. Entered HE as a mature student.</td>
</tr>
<tr>
<td>Linda</td>
<td>E</td>
<td>Left school after GCSEs to enter employment. Returned after five years to take A levels at FE and then an access course.</td>
</tr>
<tr>
<td>Heather</td>
<td>E (achieved C in re-sit during HE)</td>
<td>Passed A levels and then on to HE.</td>
</tr>
<tr>
<td>Nancy</td>
<td>E (four attempts)</td>
<td>Passed some A levels at school. Then entered FE to take further A levels and a foundation course.</td>
</tr>
<tr>
<td>Quentin</td>
<td>E</td>
<td>Left school after GCSEs to enter employment. After a few years entered FE to take a national certificate.</td>
</tr>
<tr>
<td>Rebecca</td>
<td>F</td>
<td>Left school after GCSEs to do a hotel reception course in FE and then on to employment. Later did an access to nursing course in FE.</td>
</tr>
<tr>
<td>Maggie</td>
<td>G (two attempts)</td>
<td>Left school after GCSEs to enter FE to do a BTEC.</td>
</tr>
<tr>
<td>Fiona</td>
<td>U (achieved B in re-sit during HE as mature student)</td>
<td>Failed A levels initially and was then unemployed. Entered FE to take different A levels and passed. Had various careers before choosing to take an access course in FE.</td>
</tr>
<tr>
<td>Julie</td>
<td>Fail (grade unknown)</td>
<td>Left school after O levels to take up employment. Returned after three years to pass A levels and enter HE.</td>
</tr>
</tbody>
</table>

*Table 12 – Secondary school GCSE results and access to HE*
In my sample, five dyscalculic students entered HE directly from school, five went immediately into FE and the remaining four chose to search for employment. For all of the participants in this study their ambitions to pursue an undergraduate course were not impeded by their dyscalculia, although the majority of participants took a route that involved FE as a way of reaching HE.

Six of the dyscalculic students took an access or foundation type course to enter HE. Deborah and Rebecca both took courses specific to entering nursing studies, whilst Linda was offered a mathematics entry course that was unique to her HE institution. Bradley and Maggie enrolled on foundation courses as a stepping stone to continuing their education, whilst Fiona completed an HND before applying to tertiary education. These alternative routes into HE did not require a GCSE ‘C’ grade in mathematics, however the students who were able to gain a ‘C’ grade in GCSE mathematics also struggled upon entry to HE. It seems then that attainment of the GCSE qualification had little impact upon HE mathematical performance for the participants, as described by Ellen:

> A lecturer at university said "Well, if you have so many difficulties with maths, why did you get a C at GCSE?" I was like, "Because I worked hard, that’s why." So they use it against me. (Ellen)

### 8.2.2 Influence of teachers on participants HE choices

Three of the participants cited a teacher as having a positive impact on their choice to pursue an academic career. Both Ellen and Linda were encouraged to apply by a teacher when they had personal concerns about their own abilities.

> With my Geography teacher in particular; he thought I was really bright and that I should be able to do it. So, his response was, "Yeah, you can do it. Yeah, you can do it. Yeah, you can do it," (Ellen)

Both students described having little confidence throughout their academic careers, with mathematical difficulties being the main cause of demoralising early classroom experiences. Conversely Deborah described how negative comments from a teacher had encouraged her to pursue an academic career, having been told that she was not clever enough to follow her desired career path:

> I said that I wanted to be a nurse. And she [teacher] said "Oh well, you have to be very clever and pass your exams to be a nurse”. And that had an impact and I thought "Right, I am. When I get through this, I’m going to come back to this teacher and show her that I can do this.” And I did... I went back and visited the school and
Deborah clearly felt this was a significant event in her life story, and the fact that she returned to visit the teacher demonstrated that it was a strong factor in her determination to pursue a nursing career. Although Deborah was the only student in my sample who described this type of emotional response, Pollak (2005) found this same determination when studying the attitudes of dyslexic HE learners. He cited similar examples where dyslexic students had been warned against HE by their teachers due to their neurodiversity, which seemed to encourage some students to apply and achieve success. A positive reaction to criticism was seen in one other student, Rebecca, regarding her decision to become a nurse despite being dyscalculic:

*I've had people say to me that I shouldn't be a nurse, that I'm a danger, that I'm a risk to people... I've had nurses put it to me... I shouldn't be on the wards, I'll be a danger. My saying to that is that I know my limitations. I know what I find difficult.*

(Rebecca)

Fitness to practise (see chapter 12) is one area where the suitability of dyscalculic employees is controversial, and Rebecca received negative comments about her aptitude for nursing throughout her training. This appeared, however, to strengthen her resolve to complete her degree and become a nurse.

### 8.2.3 Parental influences on choosing higher education

Most of the students have described how parents had been supportive of their career choices:

*I don't think I'd be here at this point if I didn't have my parents, because they believed in me from the word “Go” and they've been there to support me, stick up for me, and that really helped.*

(Rebecca)

This was especially true of participants in the high achievers (HAch) group and was shown to be a strong social factor in their choice of career. This is discussed more fully in section 11.3.

Outside of the HAch participants there was little evidence of parents being a reason for following an HE career. Only Alison suggested that her father had expectations for her to attend university:
I knew for GCSE you had to get a B. You couldn’t go [leave the school], it just reflected on you and my dad was like “You have to get a B at maths, you can’t not get a B” (Alison)

Even though Alison eventually attained a C grade, the strong influence of her father was possibly a significant factor. In other families there was no evidence of parental encouragement into HE. Parents were mostly aware of their child’s mathematical difficulties and supported them where possible, often with constant ad-hoc mathematics tests to the displeasure of the participants, as exemplified by Alison:

Dad would sit there in the car with time tables and I would dread it in every car journey. (Alison)

But equally many of the parents also struggled with mathematics and were unable to help:

My Dad always said he couldn’t do maths, and he couldn’t help me with maths, so I didn’t get any support from my Dad. (Deborah)

This could possibly be due to genetic inheritance as it known that other neurodiversities, for example dyslexia, have familial links (see appendix M).

8.2.4 Career concerns on choosing higher education

Concerns about career prospects were a major consideration for half of the dyscalculic students in the study, mostly those from the severely dyscalculic (SDY) group. Maggie chose to pursue an HE career in response to a fear of the quality of her work-placed life without qualifications:

Some of the jobs that you can get, some of the jobs that I’m scared I’ll end up with if I don’t go to university are working in a shop... and I wouldn’t be able to use a till. So, I want a job where I can be in control. If I’m working on a till, then the boss can come and just shout at me because I keep getting it wrong... But if I’m in a job where I’m in control of what I’m doing, I’m not going to shout at myself, I’m not going to stop myself from using a calculator or my fingers, or doing it my way. And I think if I go to university, I’ve got a better chance of doing that, instead of ending up in a rubbish job. (Maggie)

This concern is much more than just a worry about her future job prospects. It is a fear of being forced to take a retail job or similar that relies heavily on mathematics, and would not only be a source of misery for Maggie, but ensure she would never be able to excel at her work. Gerber et al. (1992) described how successful neurodiverse students
were more likely to make vocational choices that ensured that “they could be their own boss or had the flexibility to control their destiny and make significant decisions about their work” (p482).

Fiona shared the same career concerns as Maggie, but her perspective arose from having already experienced an unfulfilling career due to lack of qualifications:

I’m thinking, why slave my guts out in a job I don’t particularly enjoy, with people who I don’t necessarily, you know, would choose to spend my time with and still be poor. I might as well go to college, do something that really does fire me up and energises my whole being... But staying in the job, nothing at the end of that, it would just be rubbish pension and retirement and a house full of cats, and I don’t want that. (Fiona)

She described how her dyscalculia had presented her with many difficulties in her role as a technician, but through maturity she was able to be honest about her issues and perform the role satisfactorily. Like Maggie though, she felt that she would never be able to excel in the job and gain promotion or a career path. For Nancy, it was not just a concern about job satisfaction, but also the fear of being sacked due to her dyscalculia. She recalled when she resigned from a job whilst working at a café:

There was one night where the till was fifty quid down and I was just convinced [it was me]. It could have been someone nicked it, it could have been anything, but I am so convinced if there’s a problem with maths, it’s me, I was just like “It’s probably me. I’ll leave” (Nancy)

Pavey et al. (2009) found that this fear was also evident with dyslexic workers. In a case study with dyslexic HE student Dave, they reported that “he told of an occasion when he had difficulty filling in an application form and was asked to leave as he would be no use in the workplace” (p22). This experience had the effect of making Dave expect to lose his job in every subsequent employment, despite his rights to reasonable adjustments within legislation (see appendix N).

In my study, Linda too had been sacked from a number of jobs due to time-keeping issues linked to her dyscalculia. She had become so disillusioned with work and depressed that she took a year off, before choosing to apply to HE:

I just couldn’t cope emotionally with working life and general life, really. So, I was off for probably about a year, and then I thought, "I need some direction in my life. I need to figure myself out, what I want to do,” so I decided to take on an adult education course in Psychology. (Linda)
Even as a high achiever (H Ach), Gemma recounted difficult dyscalculia-related experiences in the workplace which had strengthened her resolve to do well in HE.

*If there's a big queue of people and it's Saturday afternoon and it gets a bit more hectic, and I have to just remind myself that they can wait for their change. Rather than just opening the drawer and looking at all the coins and not really, not understanding what they are. It's almost like you lose that knowledge momentarily, when you're panicking or under stress.* (Gemma)

These negative part-time work experiences were similar to the fears expressed by Maggie about her future. There was a perception from the participants based on experience that unqualified work often involves retail and handling money. Both in the workplace and in everyday life, financial dealings caused the dyscalculic students significant stress and embarrassment, and were to be avoided if at all possible.

### 8.3 Subject choice

This section examines the subjects chosen by the participants and the factors that led to those choices. The analysis showed that the participants’ choices followed four different trends.

#### 8.3.1 Lack of awareness of mathematical content

The first trend regarding subject choices was where the participants opted for courses that they were unaware had some level of mathematical content. There were six participants who commented that they were surprised at the mathematical content on their chosen academic course. For example, Julie had never considered that a Masters degree in History would contain advanced mathematics:

*History's always been a favourite subject of mine, and I thought I'm perfectly safe with history itself, until last term we were hit with a four-week statistics course, which I nearly crawled out the roof [sic].* (Julie)

This lack of awareness was borne out by her recollection of the syllabus of History at school, where no such explicit mathematical content existed. In subjects where the participants had no previous experience, they equally did not appear to be well informed about the mathematical content in their chosen courses. An example was Heather who felt this was due to poor careers advice from her school:

*I wanted to go to university. But again, we didn't have much career advice or anything. They just said to us "Right. If you want to go to university, have a look on their web sites and see what courses you want to do."* (Heather)
In Fiona’s case she believed it was due to her HE institutions lack of understanding around her neurodiversity. She had specifically enquired about the mathematical content of her course in Wildlife and Countryside Management before applying. She had been told that there was no mathematics, and therefore was mistakenly reassured:

*I’m sad to say, [there was] a fair bit of maths which has come as a bit of a disappointment to me... We don’t have to do the formula because there are programs to do it for you, but because of my issues, I have only got to see it and you get that response. It’s just a shutdown response in me.* (Fiona)

The HE staff who had spoken to Fiona had only considered specific mathematical modules, and not the embedded mathematics that a dyscalculic student would find difficult, such as graphical representations or measuring. Fiona therefore had to overcome additional anxiety as she was not emotionally prepared to face the challenge of mathematics on her course.

Where the participants were unable to avoid the mathematics-rich modules, they found the experience debilitating, as exemplified by Heather when she encountered an unexpected statistics component of her Psychology degree:

*I was really disappointed [at finding statistics] and I was a bit anxious and started to get a bit panicky again.* (Heather)

For dyscalculic students to be fully prepared for the mathematical content of their career choices they will need to look beyond the initial HE degree. Two participants encountered unexpected mathematics during additional professional qualification examinations post degree. Julie, in order to qualify as a lawyer, had to pass a one year Accountancy exam, which she said caused her significant stress to the level where it became a risk to her mental health (see section 4.4 & 8.4). Heather, on her PGCE primary years teaching course, had only expected mathematics to the level she would be teaching, and yet had to take a QTS mathematics test of a much higher standard. Like Fiona earlier, she had a different interpretation of the meaning of mathematics, which had serious consequences for her career options and emotional well-being. Section 3.6 explores how dyscalculic and neurotypical individuals view mathematics differently. Fitness to practise issues in teacher training are also discussed more fully in chapter 12.

Some participants had expected a certain level of mathematical content, but had been surprised by the amount in reality, as described by Ellen:
I changed from Geology to Geography, even though I knew I would probably have to do statistics if I did that. I preferred that to having maths in every subject. Oh, that was a bad choice. (Ellen)

Ellen felt she was encountering mathematics in every lecture, with no respite, and gave an example of angle calculations for rock strata:

*It came to angles in these shapes, I died a bit. I still don’t understand angles, which can be difficult, because I started doing Geology, and they like their angles. So, I dropped that.* (Ellen)

For Ellen the mathematical tasks may not have been insurmountable, but the need to consider these concepts in every lecture was demoralising and exhausting. She therefore decided to change course to avoid this amount of exposure to mathematics. Even though her new choice contained an arguably more difficult statistical component, she felt relieved that she was now exposed to mathematics in only one module.

### 8.3.2 Misplaced confidence in coping strategies

The second trend was where participants deliberately chose degree courses with moderate mathematical content believing that their existing skills or coping strategies would be sufficient. There were two participants who knowingly chose a mathematical degree (both business-related); Alison and Olivia had performed well at GCSE where hard work and procedural learning had overcome their dyscalculia (see section 10.2.1), and conceptual understanding of the mathematical topics may not have been strongly assessed. Alison had drawn upon her dyslexia for her coping strategy of visual memory skills and had always found a way to succeed in mathematics through school, and thus felt she would be able to overcome any potential difficulties:

*I knew there’d be a tiny bit [of mathematics], but I didn’t think, I just didn’t expect it to be too difficult. I thought “Okay, bit of maths. I wasn’t very good at it but I’m sure I can learn it and figure out a system and I’ll pass that side of it.”* (Alison)

Similarly Olivia had used her own personal traits of strong presentation and organisational skills to find mathematical success during her secondary education. Through her coping strategies she had succeeded in previous mathematical challenges, and felt that these mechanisms would bring continued success:

*I was aware that there was going to be maths. I didn’t necessarily know it was going to be as bad as it was.* (Olivia)
For these two participants however there grew a realisation that success at GCSE mathematics did not automatically lead to an ability to cope with the mathematical demands of their chosen degree courses. Both Alison and Olivia came to awareness that their existing coping strategies were no longer effective. In some ways passing GCSE mathematics had not given them an advantage over the other participants as they had chosen more mathematics-rich degrees resulting in the same, if not greater level of mathematical difficulty than the participants who had failed GCSE mathematics. As their existing coping strategies proved no longer to be adequate, they were compelled to seek support (see section 10.4).

8.3.3 Career driven

The third trend was that of participants who knew they would face a mathematical struggle, yet still chose to follow that course due to their resolute desire for a particular career path. Three of the students entered HE knowing that they would face mathematical challenges that they would struggle to overcome. This scenario always coincided with a determined, clear career path that superseded the desire to avoid mathematics, as exemplified by Rebecca:

But to have that, to be taken out of uni and to be told that you'll probably never nurse and never get a chance to go back ... It was incredibly depressing, because that's all I had really wanted to do and it was something that I was good at. (Rebecca)

The two health profession students, Deborah and Rebecca, were career driven in their choice of health-related subjects, which led to an acceptance that their studies would be a severe challenge. Both Gemma and Linda were also career minded in their choice of HE course, searching nationally for specific courses (Artificial Intelligence and Criminology respectively) that satisfied their individual career aspirations.

As the students in this scenario had dedicated ambitions to follow a particular career path, their chosen subjects had been well researched and there was no misapprehension as to the mathematical content of the degree courses. All the participants in this case were aware that these parts of the curricula would be challenging and provide a threat to the chance of successful graduation, yet the desire to follow their career choice was so strong that they were willing to take that risk. However career driven students have the most to lose when they are unable to cope:

The rug was pulled from underneath my feet, basically, because that was my whole, dreams, all my goals, to be a nurse, was taken from me. And I would say in that period of my life, I was incredibly depressed. (Rebecca)
Chapter 8 – Experiences leading to identification of dyscalculia

Rebecca’s desire to become a nurse had overridden any counter arguments to avoid mathematics. When she was officially identified she realised that her chosen career may be incompatible with her difficulties, which led to her quitting her course and suffering depression. She required a break of a few years and found a sympathetic doctor before she was able to continue her studies and finally graduate.

8.3.4 Successful avoidance of mathematics in HE

The final trend involved participants who had successfully chosen HE courses that avoided any notable mathematical component. There were three participants who described this strategy. Both Bradley and Nancy had chosen art degrees that did not require a GCSE in mathematics:

*I was really lucky. I did the higher education one [PGCE] because you don’t need maths to do that. If I’d gone for secondary or primary education, I just wouldn’t have been able to do it because… [of the QTS tests].* (Nancy)

Nancy continued this successful avoidance strategy when applying for teacher training, by taking a PGCE in post-compulsory education, which is a specialised course offered by very few HE institutions. She chose this route because unlike primary and secondary teacher training, the tertiary pathway does not require students to take a QTS mathematics test. Bradley’s career choices up to the time of interview were dictated by his feelings towards mathematics. Even though Bradley chose an Arts degree, he was still consciously limiting his exposure to mathematics:

*You can break into different specialisms in my course and I didn’t know whether to go for weaving, but there’s quite a lot of maths in weaves [sic]. I went to Multimedia in the end so it’s been less maths than it could have been.* (Bradley)

He had initially wanted to become a teacher, but had decided against this due to the requirement for a grade ‘C’ in GCSE mathematics. After his degree course he was considering taking an MSc in Costume Making that would require a higher level of mathematics knowledge than he had faced so far, and may have required a retake of his GCSE. At the time of the interview he was still unsure how to proceed.

Although Deborah could not avoid mathematics completely in her health profession career, she did make choices to limit the amount of mathematics where possible:

*I chose to do adult nursing as opposed to paediatrics, because the paediatric… you’ve got a lot of calculations to do with drugs and I couldn’t even face going into that branch of nursing because I knew that I’d struggle with that and I’d be really embarrassed about it and self-conscious.* (Deborah)
Deborah had successfully navigated a long career through nursing, midwifery and now medicine despite her dyscalculia. Although she was able to employ an array of active coping strategies to overcome her difficulties, she would still resort to avoidance where possible. This is also discussed in chapter 12 within fitness to practise.

8.4 Mathematical anxiety

This section explores the nature of the mathematical anxiety (MA) and other forms of general anxiety described by the participants. Special consideration is made to the effects of MA on working memory and the consequences of this.

8.4.1 Mathematical anxiety related to numeracy

All the participants within the study described experiencing MA whilst in higher education. All of the three responses highlighted by Sheffield, psychological, physical and biological, were in evidence (see section 4.4.1). Physical responses were described particularly strongly by the participants, with numerous occurrences for each student and the severity of the anxiety was often extreme, as exemplified by Heather:

_ I just get really sweaty and I start to get my heart beating and I just get really dizzy and a tight chest... I just start flooding with tears. (Heather)_

Other descriptions included clammy hands, sweatiness, feeling warm, tension, raised heart rate, dizziness, tight chest, inability to breathe, turning bright red, clenched teeth and tears. This array of physical responses corresponds to previous definitions of MA (Tobias, 1978; Ashcraft & Faust, 1994) that focussed mainly upon the visual bodily effects.

Many of what Sheffield referred to as psychological effects were also described, as illustrated by Linda:

_ I had a sinking feeling, really. I would just think, "What's the point?" (Linda)_

The psychological responses recounted included a sense of fear, dread, a sinking feeling, panic, "freaking out", meltdown, embarrassment, shame and a "nervous breakdown", and again are consistent with existing literature (Arem, 2002). The narratives provide strong evidence that all the dyscalculic students within the study have struggled with MA not just during higher education, but throughout their academic careers and everyday experiences. MA had become such a constant part of the participants’ lives that a few began to assume it was a commonplace phenomenon experienced by all students, as described by Deborah:
Tables, tests and stuff like that filled me with dread, but I didn't really think about, maybe other people had that, I thought perhaps it was everybody that was stressed.
(Deborah)

MA is not synonymous with dyscalculia, and many neurotypical students also struggle with mathematics-related stress. However there is no evidence from my data or anecdotally of a dyscalculic learner never having experienced MA at some point, although its existence is not part of any official definition of dyscalculia. The participants described their first recollection of MA at varying points in their education. There were a few students who recalled initial instances in primary education, although most participants recalled their first experiences of MA during secondary school. Julie was the only student who described the initial onset at a later point in her academic career, which was after her degree. She believed this was because, as a mature student, her secondary education was "traditional" and very procedural in teaching-style, and she was able to cope psychologically with this type of pedagogy (see section 10.2.1). It was not until she needed to pass her accountancy course on her higher education law degree that she was required to attain a level of conceptual understanding in mathematics.

The third of Sheffield's responses, the biological effect, was most in evidence when the participants described a mental block. Olivia had an adverse reaction brought on by just seeing numbers, and she described how disabling this was:

As soon as you put numbers in [to a problem]... I can't do it anymore. And I don't know whether that's a mental block or whether it's actually that I can't do it. But it really does confuse me. As soon as you start saying numbers, I'm just like, "I don't know what you're talking about. (Olivia)

This ‘mental block’ is explored in more detail in section 8.4.4 as it is a critical characteristic of MA and a common experience for the participants. Due to Olivia’s high levels of MA, her trigger point was the mere visualisation of Arabic numerals, even before undertaking a difficult mathematical task. More typically the participants were affected whilst trying to perform a numerical operation. Julie also struggled with an anxiety episode that was triggered visually by Arabic numerals, but her example was more unusual. She described being unable to touch type numbers, despite being an experienced typist for many years:

When I left school I did a secretarial course and I was taught to touch type on a big old manual typewriter. And of course, you learned how... so that you can look at what you're doing and just type. And I can still touch type very quickly, but I have never ever been able to touch type the numbers. I cannot touch type numbers. I have to look every time to do the numbers. (Julie)
Although Julie did not directly report any psychological effects in this case, such as feelings of anxiety, this biological effect was an inhibition of her ability to process numeral characters.

### 8.4.2 Mathematical anxiety related to statistics

It was evident from the students’ narratives that feelings of MA were not only associated with arithmetic, but could also be triggered by graphical representations:

*As soon as she put a PowerPoint up and there was your first graph, I’m like “Oh no, here we go”... as soon as it appears on the screen, that’s when I struggle, from that point when it pops up and there’s numbers and symbols, and there’s graphs and there’s this and there’s bars... so I then get all, you know, anxious and upset and just stressed.* (Fiona)

Fiona recognised various visual signs that represented mathematics to her and thus triggered an anxiety reaction. Arabic numerals and mathematical symbols such as operators are predictable triggers, and for Fiona, graphical representations (see section 9.5.2.4) had the same effect. When Fiona applied to her HEI, she asked the prospective lecturers whether the course contained mathematics. The reply was that there was some statistics involved, but not to be concerned:

*The lecturers would say it’s not really maths, but to me, I’m afraid, it’s maths.* (Fiona)

Fiona’s lecturers did not recognise that graphical representations could be a major cause of difficulty for a dyscalculic student, and therefore a potential source of extreme anxiety. The participants’ accounts show that triggers for MA go beyond counting to include the visual recognition of any mathematically-related stimuli. Hembree (1990) alluded to this when he suggested that MA does not stop at opening a mathematics textbook or entering a mathematics classroom; an activity such as reading a till receipt could cause a panic attack.

As HE statistics were often the only mathematics that many students had to face, ‘statistics’ had become an emotive word that caused a strong negative response.

*If you put me in a specific maths lecture now, like statistics, if you put me in a lecture and I know that it’s statistics, I already know I can’t do it before I go in. Whereas if you send me to... If I was in a geography lecture and in the middle was statistics, I might actually be able to do that statistics, because I’ve not worried about it for three days before.* (Ellen)
Here Ellen displays self-awareness and recognises that the fear of statistics is actually compromising her ability to perform mathematical tasks successfully. She had become so demoralised by the subject that she had resigned herself to failure before entering the lecture theatre. In Ellen’s case the word ‘statistics’ was the trigger for the onset of MA.

### 8.4.3 Other mathematics-based anxieties

As well as anxiety provoked by contact, or the thought of contact with numbers, anxiety can be exacerbated by other related factors such as examinations or fear of failure. These external anxiety factors could of course be attributed to any student performing any task, and it is therefore difficult to assess how much of this is related to mathematics. For Quentin, anxiety is a mental health issue which permeates every activity, and hence it is difficult to extract the MA from his general anxiety issues. The boundaries between general anxiety and MA are unclear.

From the data the most evident external factor to have an impact on the students anxiety was time pressure. This supported the claim by Chinn (2009b) that “for students there is often a perception that the expectations about mathematics skills are unrealistic, for example, in the requirement to answer questions quickly” (p61). A time limit on a mathematical task appeared to cause significant extra pressure for the participants, increasing the levels of anxiety as described by Olivia when talking about performing arithmetic:

\[\text{The worst thing is, if you put pressure on me, then I become flustered and I can’t do anything. (Olivia)}\]

Reported examples of being asked to perform mathematics under time pressure were not only educational, such as examinations or tests, or being selected by a lecturer to answer a question in class; a commonly cited non-academic situation was that of being at the front of a queue, when there is social expectation that a transaction is performed efficiently. Nancy recalled an occasion when she tried to remember the access code to a university building frequented by her peers. She had to retrieve a written code from her bag and then struggled to type the code correctly, causing a queue to form behind her. She found the experience so stressful, that she subsequently avoided using that particular building, and worked in the library instead:

\[\text{I get to the keypad. I don’t have a bloody clue what the number is… this will be my fourth academic year… So I will have it written down in my diary and then that means me getting my diary out and then I try putting it in and then it will have been wrong and then I have to try again and I’m still stood there and there is someone behind}\]
me, and I just feel like an idiot... I just take myself out of that scenario now and just don’t go in to work. (Nancy)

This episode demonstrates the alienating nature of MA. As Nancy has chosen to work elsewhere, she has missed out on social contact with her colleagues by not having access to the main building:

[The keypad issue] means that I will be quite isolated... It would be nice to be able to pop in and say hello and have a cup of tea every now and then. (Nancy)

Paying at a till was another stressful experience for most of the participants due to the mathematical nature of the transaction process, and is discussed further in section 9.5.3.1.

Another important anxiety reaction relevant to a subset of the sample was concern about career-specific issues. These affected the students who would have to perform mathematical tasks in their chosen career, and who were already being tested in placement situations. Known as ‘fitness to practise’ and especially relevant to teaching and subjects allied to medicine, this is a highly important topic and is discussed fully in chapter 12.

8.4.4 Mental block and working memory

As well as the physical and emotional effects of anxiety, many of the students described a ‘mental block’ at times. The participants described an inability to think clearly and rationally when encountering numbers, as if mental processes had been ‘switched off’. The participants recounted this sensation vividly, and each student’s metaphor had a striking similarity to others. Bradley referred to this experience as haze and mist:

If you told me to think of a sequence of numbers I could get them but they wouldn’t be in the right order, all kind of weird, hazy, mist across them that doesn’t allow me to get to the right answer. (Bradley)

Ellen referred to the phenomenon as a brick wall:

It’s like it might as well be a brick wall. I have to get through a brick wall before I can even attempt to do any kind of calculation or whatever... It’s like all in compartments in my brain. It’s all there, but I can’t put it all together. (Ellen)

Fiona compared the experience to having shutters in her mind:

I’ve gone past the point of no return in a way and that’s when the shutters will come down and my brain is kind of going “You can’t go there because it’s actually going to
cause you anxiety and stress so don’t go there” and then it’s just “Can’t do it”. And at that point I know that there’s not a lot of point in even trying. (Fiona)

Quentin meanwhile, referred to the mental block as treacle:

Mentally, it would be that my brain would just stall. Suddenly, everything would just turn to treacle. (Quentin)

This mental block is a characteristic of MA, rather than directly attributed to dyscalculia, and refers to the apparent loss of working memory (see section 4.4.2). The participants’ metaphors illustrate how working memory capacity had been reduced and how the students could no longer formulate and construct the desired mental processes.

Due to these mental blocks, the dyscalculic students had difficulty imagining numbers and organising them mentally to complete the task as exemplified by Bradley:

If I wrote it [arithmetic problem] down I could do it, but I can’t visualise [it], even thinking about it now it’s like a wheel that can’t turn. (Bradley)

The prevalence of these similar accounts regarding mental blocks implies that dyscalculia is strongly associated with poor working memory, but does not explain the relationship or the triggering factors.

Conversely however, Alison described having excellent recall and reported no issues with the visuo-spatial aspect of her working memory, which is one of the memory components used for numerical manipulation:

I’ve got a good memory, that’s how I remember all my spellings. So I just remember everything, and when I learn I can sit and see a piece of paper and then I know where everything is on the piece of paper. (Alison)

It is likely that this is because Alison has a co-occurrence of dyslexia, as strong visual memory skills are a key characteristic of that neurodiversity (dyslexia-related working memory issues are usually associated with the phonological loop (see section 4.2.2.4) or central executive (see section 4.2.2.1). Although Alison described several features of MA, the ‘mental block’ characteristic was not one of them. Alison, by using her visual memory strengths had been able to counter some of the negative impacts of MA when internally processing numbers.

8.4.5 Coping strategies for mathematical anxiety

The participants were all fully aware of their anxiety issues and able to discuss them openly. None of the participants had developed a coping strategy to alleviate the effects
of MA, beyond complete avoidance of the mathematical situation. Linda would miss seminars to avoid the stress associated with the non-comprehension of mathematical ideas:

*It was usually dread [sic] to be honest. I would be on my way to the class and think, “I can’t go. I’ll do something else.”* (Linda)

The use of an escape-avoidance strategy (see section 4.4.4) was common amongst all the participants, especially those in the severely dyscalculic (SDY) and highly anxious (HAnx) categories. Heather, for example, once felt compelled to leave a lecture expeditiously rather than continue with a mathematics-related task:

*So I have had a couple of panic attacks which has been awful. I had to run out the classroom...* (Heather)

Heather’s reaction could have repercussions, as not only might it cause embarrassment, but it could be seen as a reason for her lecturers to doubt her suitability for teaching. In a similar way to Nancy’s keypad access issues, the anxiety was having a profound inhibiting effect on Heather being able to integrate into her chosen community of early-years student teachers. These experiences were disabling for the participants and frequently led to a strategy of mathematics avoidance (see section 4.4.4).

Although all participants described periods in their academic careers where MA was a major issue, two of the students, Alison and Olivia, felt this was now less of a problem. This may be because they had received timely and knowledgeable support that had given them practical skills to perform mathematical tasks and instilled a greater confidence around numbers, which in turn had helped them develop their own coping strategies. Some of the students described having just begun support sessions at their institutions, whereas the remaining students had received sporadic or no support during HE. The effectiveness of this support in terms of mathematical learning is discussed in section 10.4.

The mature students in the sample discussed disclosure as a positive means of addressing MA. By being honest with others about their mathematical difficulties, they were able to avoid mathematical situations by delegating responsibility to others.

*I’m too old to care now. Got past that point of embarrassment... Now, I just kind of go, “I can’t do it. Give it to somebody else.”* (Fiona)

Chinn (2009b) stated that in contrast to core literacy skills, "it appears to be socially acceptable to admit to having low abilities with numbers, a situation that lowers anxiety
in adults” (p61). So the strategy of disclosure, acknowledging the difficulties within their peer group, helped the participants use avoidance as a strategy and negotiate delegation or shared workload that limited contact with mathematical tasks.

8.5 Process leading to the formal identification of dyscalculia

This section describes the processes and circumstances involved in the participants’ identification with dyscalculia, and their reactions to the experience.

8.5.1 Timing of the formal identification of dyscalculia

Ten of the fourteen participants were assessed for dyscalculia while in HE, which is a similar proportion to the 74% percentage figure reported by Drew and Trott (in press). None of the participants in the study was formally identified as dyscalculic prior to leaving secondary education. For the mature students in the study, their school may have recognised a mathematics difficulty but misunderstood the cause, mainly due to the lack of awareness of dyscalculia at the time, as suggested by Nancy:

At secondary school... they never even used the word dyscalculia and I wasn’t aware of it until college, and I don’t think the schools were really. (Nancy)

The lack of early identification was described as being no better for most of the younger participants. They often reported that their parents were aware that they struggled with mathematics during primary or secondary education, but had assumed that the school were the experts and would recognise if anything was wrong. In the one case where parents had forcefully questioned the progress of their child with the school, the extra concern and proactive support had not led to an earlier formal identification; Rebecca’s parents actively challenged the school to explain her difficulties and provide her with additional help:

Mum and dad were fantastic, they fought for me, they fought my corner and they would say to the teachers, "There's something not right here."... The teachers always came back to my parents saying, "She's developing at a normal rate for a child of her age; there are no problems; there's nothing," and Mum and Dad weren't satisfied with that. But however much they [parents] fought, they [the school] wouldn't budge. (Rebecca)

Rebecca’s parents kept a diary of her experiences, and included newspaper cuttings of reports on dyscalculia, even before their daughter was formally identified as dyscalculic.
Out of the eight participants who studied at an FE college prior to entering HE, there were three who were formally identified during FE. Significantly, this was three of the five severely dyscalculic (SDY) participants who studied in FE. The two SDY participants who were not identified during FE both commented that their FE course had minimal mathematical content. From the data it is impossible to comment on the general effectiveness of the FE institutions in recognising and supporting dyscalculia, however in this sample SDY participants undertaking some mathematical curricula had been identified. None of the three FE moderately dyscalculic (MDY) participants were identified during FE, although two of those participants are mature students and it had been some time since their previous tertiary education, and advances in dyscalculia awareness, and legislation, have since been made.

8.5.2 Events leading to formal identification of dyscalculia

For all but two of the participants who were formally identified during HE, the decision to seek help was prompted by either a statistics module (see section 9.5.2) or a fitness to practise issue (see chapter 12). I was aware anecdotally of the difficulties caused by statistics, and this was supported by the subjects chosen by participants; they avoided the physical sciences which are known to contain a high level of mathematics, and instead were drawn towards arts or social science courses (see section 8.3). For all the participants not formally identified with dyscalculia until HE, help was sought as a result of struggling in their new environment, having become increasingly aware that their existing coping strategies were no longer adequate:

*I came to university and because the support of the teachers isn't there, it suddenly hit me that I... needed help somewhere. And my Dad was like “Well, you can have tests like if you need it, you're obviously struggling. Just go and have some help”.*

(Alison)

Alison had been successful at school and was confident that she would find a way to cope with the mathematics on her course. Like most of the participants in the co-occurrence of dyscalculia with dyslexia (CDD) and high achievers (HAch) categories, she overestimated her own coping strategies and began to struggle, and even considered quitting the course. Instead she chose to seek help, and attended a mathematics drop-in centre, an event which then led to more specialist help and screening for SpLDs. The only participant of these two groups who told a different story was Bradley, who as an Arts student, was still reasonably comfortable with his existing coping strategies and chose not to opt for one-to-one mathematics support.
Most of the participants were prompted to seek support by a friend or teacher who recognised the likelihood of a specific learning difference, as explained by Heather:

[My lecturer] was the one who actually said to me "Have you ever been to see an Educational Psychologist?" And she gave me all the details of one and I had to go and see him. (Heather)

Fiona’s chance discussion outside of education with a knowledgeable family member was the trigger for her inquiring about help:

My sister-in-law was a SENCO [Special Educational Needs Co-ordinator] at the time... and she said "Well it sounds like you might be this thing called dyscalculia" and I’m like "What? Never heard of that!" So I bought it up in the class when I joined and they said, "We can get you tested". (Fiona)

Similarly, Nancy was fortuitous by being taught by a lecturer with personal family experience of dyscalculia, beyond his normal training:

[My lecturer] was going "There’s an issue with maths here, because you are doing really well with everything else.” It was because one of his daughters was dyscalculic... I was lucky. So it was him that went and said "Right, we need to get you tested". (Nancy)

Although most of the participants who were identified during HE received independent advice, they all contacted their learning support department of their own volition:

I went on my own accord. I asked for some advice from one of the Geology lecturers that I had, and said, "I'm getting a bit concerned now," because it’s not exactly like I’m stupid or anything and I’m not below average intelligence. But yet, I still can't do simple maths. They just said to me “I think you’re just exaggerating.” I thought "You know what? I’m going to get a test anyway.” So I went and asked in Accessibility "Can I have a test?“ (Ellen)

In addition, all the participants in the study described a well-advertised and readily available learning support system at their institution:

I think I was on one of the university computers and they have a pop-up that comes up when you log in. I thought, "What's that?" And I read a little bit and I thought, "I wonder if that's me, because I'm terrible with maths." So I e-mailed the department, got an appointment, came in and was diagnosed. (Linda)
8.5.3 Screening and assessment

At interview, most of the participants reported little recollection of the actual dyscalculia identification process. Although many could recount detailed stories of the events leading up to formal identification, and the subsequent events of applying for Disabled Students Allowance (DSA) to gain support (see section 10.4), the identification process itself was not an event that many particularly remembered. Without prompting, none of the participants mentioned screening, and only four of the participants discussed the Educational Psychologist assessment process. I believe this lack of recollection should be viewed positively, as it suggests that for most of the participants, identification was not a traumatic process, as illustrated by Heather.

*I didn’t get that frustrated actually, because I knew he [Educational Psychologist] was there to help me. He wasn’t there to judge me and to teach me things. It was just, do my own thing. And I wasn’t that anxious or anything. It was quite surprising, I was expecting to be in tears.* (Heather)

It was surprising that neither participant in the highly anxious group (HAnx) described the assessment process in particularly stressful terms. This may be due to a relative perspective of how they experience mathematical anxiety in real life, or alternatively as suggested by Heather, because the assessment process was not experienced in isolation as they were accompanied by a supportive empathetic practitioner. Three participants, however, did describe severe feelings of stress during the assessment, which is unsurprising given the high levels of mathematical anxiety described by the students in academic and everyday life:

*It was quite a mammoth session... a really nice lady who did it and she could see that I was getting anxious and stressed at one point. There was loads and loads of tests, but as soon as she put a sheet of paper on the table with sums on it, it’s like, “See how far you can get”. I immediately have sort of sweaty palms, just generally overheated and agitated and my anxiety level starts to rise, and she’s like “I’m sorry I have to make you do this”.* (Fiona)

Fiona understood the importance of the assessment in gaining the support she needed to undertake her course, but her feelings of anxiety still arose and prevented her from accessing the questions. Similarly Deborah experienced the sensation of "being under pressure", and Maggie described leaving the assessment with "a terrible headache". The welfare of dyscalculic students during the assessment process should be a concern as an episode of MA may occur.
All the participants who had been formally identified as dyscalculic whilst in FE were re-assessed as the HE support process requires a recent identification of dyscalculia (within the last five years). EP assessment from FE is valid but the needs assessment process must be relevant to HE (see section 5.6).

### 8.5.4 Student reactions to formal identification of dyscalculia

Although there were some concerns, all but one of the participants expressed a strong positive reaction to being identified with dyscalculia:

> I felt, after the assessment with Lucy [Educational Psychologist], it was a massive relief, to go "Oh there’s a reason I can’t do this." It explains so many things in my life that I struggle with. It’s not just that I can’t count very well and I can’t deal with numbers, it’s the timekeeping, it’s the spatial awareness, it’s the working with patterns and sequences. (Fiona)

The most common reaction was a sense of relief that an explanation had finally been provided that accounted for all the mathematical difficulties. Although identification had not changed their neurodiversity, it had removed the sensation of being "stupid" that was described by all the dyscalculic students.

> It was like a weight had been lifted off my shoulders. You know, this weight from all these years that I thought "Oh, God", and "I can't do this. I'm really thick." (Deborah)

The feeling of being intellectually inferior was a constant theme throughout the participants’ narratives. Sometimes the participants had been derided for their intelligence by teachers or peers, but more often it was a self-created opinion informed by peer comparison. Therefore identification had a major impact on the participants’ sense of identity.

Some of the students felt the provision of support was the greatest effect of being identified with dyscalculia:

> I went and got a dyslexia test and then they realised I was dyscalculic at the same time and they said "You can have maths support” and I was, I thanked the Lord. It was the happiest day I could have had. (Alison)

Although the participants did not often refer to the processes around assessment, they were aware that they required an official identification of dyscalculia to be entitled to DSA funding and therefore gain access to dedicated one-to-one specialist support. In most HEIs, support can only be provided via funding from a DSA.
There were also negative emotions amongst the overriding sense of relief. For two participants there was some sense of anger that it had taken so long to become identified, as described by Nancy:

*A little bit angry because school was so horrific. I was angry that it had taken that long for someone to go "This is what's going on..."* (Nancy)

Failure of organisations to recognise a student as dyscalculic and provide support at an earlier age was a cause of resentment for a few participants, notably those in the *severely dyscalculic (SDY)* category.

For most participants, passing mathematics modules on their HE course was a means to an end to graduating but for some, where fitness to practise issues were relevant, the impact was much more significant:

*There was one side of me that was, "Oh, thank goodness; I'm not actually stupid, there is actually a reason for it"... But then, the flip side was that the rug was pulled from underneath my feet, because that was my whole, dreams, all my goals, to be a nurse, was taken from me.* (Rebecca)

As a student nurse, Rebecca was aware that the ability to handle mathematical tasks such as drug calculations was a necessity for her chosen career, and before identification she believed that she would find the coping strategies to succeed. Having been ‘labelled’ as dyscalculic, she now feared that she would not be given the chance to succeed, and that dyscalculia would automatically disqualify her from her dream. For her the initial identification was devastating.

One reaction expressed by three participants was concern that identification could be used as an excuse for not pursuing academic targets. Like other neurodiverse students, all the students in my study recounted how they have had to work harder than their peers to achieve success and reach HE (Humphrey & Mullins, 1999). Some of the participants therefore wondered whether an earlier identification would have been a barrier to achievement.

*It's kind of a relief that I know that I'm not stupid and that there is some kind of problem, but also it's kind of like made me less determined because before I was like I need to succeed in maths and I'm going to try and force myself but now I'm just like I'm not going to.* (Bradley)

Both Nancy and Fiona had noticed this lack of ambition since being identified as dyscalculic, by choosing less challenging paths and giving up more easily:
I’ve always put a lot of pressure on myself to attain and I was not attaining. I think it [dyscalculia identification] probably gave me the excuse not to push myself as much I should have, perhaps, when it came to trying things like driving. (Nancy)

On being identified as dyscalculic, there could be a risk of a student accepting that they will be unable to succeed in some areas, and this behaviour has also been associated with dyslexia (Tanner, 2009). It may prevent some students from attempting certain highly challenging careers, but equally it may dissuade a student who may otherwise have overcome those difficulties and reached their goals. Fiona described how dyscalculia now gave her an excuse to fail:

I think, when I was younger, certainly as a teenager, young adult, you do mind failure because it becomes a bit of stigma then, but certainly since the diagnosis, I’m like “Hey. That’s fine. I can fail now. It’s alright.” (Fiona)

This reaction was mostly associated with participants who had adopted a more medical model view of their dyscalculia, who Pollak would describe as a patient or syndromist (see section 2.3.3). This could be seen as a ‘double-edged sword’. Whilst it could possibly help a student come to terms with failure, it could also be used as an excuse not to try to achieve goals of which they would otherwise be capable, and to use dyscalculia ‘as a crutch’. It is therefore important that reactions to dyscalculia are appropriately handled post identification, and the dyscalculic student receives on-going support that focuses on potential achievements rather than limitations.

When Ingesson (2007) interviewed Swedish dyslexic adults about their reactions to being indentified the reaction was mixed. Half expressed the same sense of relief shown by all the dyscalculic students, while the other half related a sense of embarrassment at being dyslexic. This was not a common reaction in my study, as only one participant, Deborah, showed concern at being stigmatised by being dyscalculic (see section 11.3.7). One participant even related a sense of pride at being recognised with an unusual neurodiversity.

8.6 Summary and discussion

None of the participants had been officially identified during primary or secondary education, although they all described significant negative experience of mathematics during that time. This negativity was not only related to their difficulties understanding mathematics, but to how they were perceived by teachers and others students, which had a profound effect on how they viewed themselves as a student and as a mathematics learner (see chapter 11). The participants described these negative school
experiences at great length, although much of the data had to be excluded from analysis as it was not directly relatable to HE. It is hoped that a future study might be able to re-examine this data. The negative experiences in school indicate a breakdown or lack of suitability of the mathematics classroom with regard to the needs of the participants. What is striking, however, is that these poor experiences, for the limited number of participants in my sample, did not ultimately discourage them from continuing their education into FE and HE. This could be because the participants did have positive classroom experiences of shared communal learning in non-mathematical subjects, and they had assumed that with suitable mathematics avoidance strategies, the negative experiences would not be repeated. As my study only included HE students, it must be realised that dyscalculia is likely to have had a significant impact on many dyscalculic individuals who failed to reach HE, or chose not to continue their education, despite having the ability in non-mathematics subjects. It is known that neurodiverse secondary school students in general are less likely to continue an educational path than their neurotypical counterparts (Weiss et al, 2012). Drew and Trott (in press) found that the prevalence of known dyscalculic students in HE is far lower than dyslexic students, whereas prevalence rates within childhood are similar between the two neurodiversities (see appendix I). Dyscalculia research is thought to be some 20 years behind informing the understanding of dyslexia (Wilson & Dehaene, 2007).

It was my assumption prior to the study that dyscalculic students entered HE by attaining a GCSE ‘C’ grade in mathematics despite their mathematical difficulties. Although there were examples where participants had achieved this standard whilst at secondary school, this was the exception, with most participants finding alternative routes into HE via access courses in FE. Passing GCSE mathematics did not appear to prepare the student for the mathematical challenges of HE. Some of the participants were able to attain a mathematics qualification at a later point when they had access to one-to-one support and had developed better coping strategies.

The participants mainly described three factors that influenced their decision to apply to HE. Encouragement from a teacher appeared to be a strong factor for some, who felt they would not have pursued an academic career without this support from school. One participant also described how negativity from a teacher had galvanised her determination to apply, a phenomenon which Pollak (2005) also described with dyslexic HE students. Another strong theme was concern over career options. Student in the severely dyscalculic (SDY) category in particular voiced concerns that without suitable qualifications they would be forced to take ‘dead-end’ jobs where they would have little control over what mathematics they had to face daily. They felt their dyscalculia would be highlighted and prevent them from being successful in the workplace. By getting a
degree they felt they were gaining agency over their relationship with mathematics. This concern over future employment was also observed by Madriaga (2007) with dyslexic HE students:

_A major factor as to why these students have furthered their education is that they did not want to work in ‘dead-end’ jobs. A few of them had experienced working in ‘dead end’ jobs and saw higher education increasing their chances for better employment prospects (Madriaga, 2007, p404)._}

Concerns about future careers did not affect just the SDY group. Although all but four of the participants entered HE or FE directly from school (see table 13), many of them had worked part-time in retail-based jobs, and their negative experiences had reaffirmed their need to gain qualifications to avoid a service-based career. The participants felt that by gaining HE qualifications they would be more able to take control of their workplace choices and manoeuvre themselves into positions where their dyscalculia would be less noticeable and would not limit their career opportunities.

When looking at the reasons why dyscalculic students chose particular subjects at HE, I found factors which influenced the participants into following one of four different trends (see table 13). Previous research by Trott (2003) had suggested that dyscalculic students strongly avoid HE courses with high mathematical content, but a strict strategy of avoidance was only part of the picture that emerged. The most frequently described trend in my sample was that in which participants were unaware of the level of mathematics in their chosen course, and as a result were surprised when they encountered mathematical content. Anecdotally, the example of a psychology student having to undertake an unexpected statistics module is often described by learning support practitioners. There was a second trend where participants had successfully avoided mathematics by choosing Arts-based courses. A third trend was where participants had found some success during school due to their own self-developed coping strategies, which gave them misplaced confidence to attempt subjects with some mathematical content. For the two participants in my study who described this trend, there was a realisation that their existing coping strategies were no longer adequate and that additional support would be required. The fourth trend was one in which participants were so determined to pursue a particular vocation that they deliberately chose subjects where they knew that the mathematics would cause them considerable difficulty. These participants were career driven, having a strong affiliation with a specific career path.

Although some participants described a combination of these trends, each participant did appear to strongly align with one of them. What was notable was that there does not
appear to be any correlation between subject choice factors and the dyscalculic HE categories described in section 7.6.

<table>
<thead>
<tr>
<th>Subject choice trend</th>
<th>Participant</th>
<th>HE Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of mathematics awareness</td>
<td>Ellen</td>
<td>Degree Geography, Masters Sustainable Management of Natural Resources</td>
</tr>
<tr>
<td></td>
<td>Fiona</td>
<td>Foundation Countryside &amp; Wildlife Management</td>
</tr>
<tr>
<td></td>
<td>Heather</td>
<td>Degree Early Years Education, PGCE Early Years</td>
</tr>
<tr>
<td></td>
<td>Julie</td>
<td>Degree Law; Masters History</td>
</tr>
<tr>
<td></td>
<td>Maggie</td>
<td>Foundation Science</td>
</tr>
<tr>
<td></td>
<td>Quentin</td>
<td>Degree Psychology &amp; Sociology, Masters Psychology</td>
</tr>
<tr>
<td>Misplaced confidence</td>
<td>Alison</td>
<td>Degree International Business</td>
</tr>
<tr>
<td></td>
<td>Olivia</td>
<td>Degree Management Science</td>
</tr>
<tr>
<td>Career driven</td>
<td>Gemma</td>
<td>Degree Artificial Intelligence &amp; Computer Science</td>
</tr>
<tr>
<td></td>
<td>Linda</td>
<td>Degree Criminology</td>
</tr>
<tr>
<td></td>
<td>Rebecca</td>
<td>Degree Nursing</td>
</tr>
<tr>
<td>Successful avoidance</td>
<td>Bradley</td>
<td>Degree Multimedia Textiles</td>
</tr>
<tr>
<td></td>
<td>Deborah</td>
<td>Degree Midwifery, Access to Medicine, Degree Medicine</td>
</tr>
<tr>
<td></td>
<td>Nancy</td>
<td>Foundation in Art, Degree Art, PGCE Higher Education, Masters Art, PhD Psycho-Geography &amp; Art</td>
</tr>
</tbody>
</table>

Table 13 – Subject choice decision factors

Anecdotally there appears to a relationship between the subjects chosen by dyscalculic students in HE and the students that are seeking learning support, which is shown in figure 18. Dyscalculic students who choose Arts subjects may be less likely to seek help and therefore become identified, as these courses have little mathematics to take the student out of their comfort zone. Arts subjects may contain some embedded
mathematics, such as measuring materials or calculating paint mixture ratio, but the transition from 'A' levels or foundation courses to degree is less likely to introduce a new mathematical concept for which the student has not already formed a coping strategy.

Figure 18 – Demographic of supported dyscalculic students

Subjects with minimal mathematics are more likely to have a high prevalence of dyscalculic students who are comfortable with their existing coping strategies. As the students are not being stretched mathematically they are less likely to seek support. Many dyscalculic students taking subjects such as Arts may therefore be unknown to learning support.

The HE courses in which officially identified dyscalculic students are most prevalent appear from the sample to be the social sciences, which often contain a small but challenging amount of mathematical content. The most common mathematical component discussed was statistics, and this was the focus of most dyscalculic student's difficulties in this sample. Dyscalculic students tend to avoid the hard sciences due to the high level of mathematics, and therefore are rarely found studying these types of subjects. The few who are studying hard sciences are most likely to be high achievers (H Ach). Further prevalence studies with larger samples would be needed to verify whether the pattern described here can be repeated.

Mathematical anxiety (MA) was shown to be the most significant factor affecting dyscalculic students’ participation in social learning activities. Although an inability to perform mathematical tasks could cause embarrassment and lead to subsequent
avoidance strategies, it was the strong negative emotional response to MA that was the main driver behind many of the participants’ avoidance strategies. This aversion prevented the student from participating in shared learning experiences, and suggests there is an important need for specialist one-to-one ‘scaffolded’ support.

All participants in the study reported experiencing strong feelings of MA at some point in their lives, and for most participants this was an ongoing issue. The onset of MA was not only triggered by academic mathematical tasks, but by the visualisation of mathematical representations, such as numbers, symbols and graphs. Statistical anxiety was particularly prevalent due to the high occurrence of statistics in HE courses favoured by dyscalculic students. MA was also commonly triggered by mathematics in everyday life situations such as shopping or the use of keypads.

MA was described as a major contributing factor to how the participants related to mathematics and led to them seeking identification, and this thesis has explored the effects that inhibition of working memory caused by MA can have on learning and performing mathematics. Recognition of the relationship between dyscalculia and MA raises concerns about research attempting to link dyscalculia and working memory, without considering the influence of MA (Geary et al., 2007). MA is often discounted by cognitive researchers. This may be due to a perceived lack of influence on dyscalculia or because of difficulties in designing tools that can separate anxiety from dyscalculia. The Havana group (Reigosa-Crespo et al., 2012) acknowledged this dilemma by stating that "math anxiety or attention disorders could also be related, but they have not been fully explored” (p132). In a review of literature attempting to find links between working memory and dyscalculia (McLean & Hitch, 1999; D’Amico & Guarnera, 2005; Snowling, 2005; Andersson & Lyxell, 2007; Dowker & Kaufmann, 2009; Landerl et al., 2009; Rotzer et al., 2009), there was no evidence of MA having been considered as a contributing factor to results. The fact that MA and dyscalculia are two separate yet highly correlated phenomena, has been known for some time, but often appears to be forgotten in dyscalculia research. It has been shown that with appropriate mathematics support, MA can be reduced and this can have a substantial positive effect in ‘freeing up’ working memory which is needed for the dyscalculic students’ preferred procedural learning style, which is highly dependent upon memory (see section 4.2). In previous research, the inhibition of working memory caused by MA had been observed in children performing memory tasks. In this study, the adult dyscalculic students were able to articulate the effects of this lack of working memory, and used strong metaphors to describe how it felt. A recent dyscalculia conference in Loughborough was entitled ‘Mist, Haze and Shutters’ reflecting the descriptions used by participants of the effect of working memory issues on their mathematical thinking processes.
The participants described only one coping strategy to deal with MA, which was avoidance. Section 10.5 hypothesises that if more effort could be made to alleviate the resultant effects of MA, then some underlying dyscalculic issues could be addressed. The two students in the sample who were known to have received dedicated, specialist one-to-one dyscalculia support over a period of time described being less likely to experience MA than before they received this support.

All participants in the study were identified during post-secondary education, with most being identified upon reaching HE. Even when concerned parents had contacted participants’ secondary schools, this had still not led to early identification. For many participants the need to seek help was prompted by the inadequacy of existing coping strategies when faced with the higher demands of HE. For others it was the sudden appearance of unexpected mathematics, commonly a statistics module in an otherwise non-mathematical course. The emphasis on mathematical competence within ‘fitness to practise’-related courses such as nursing and teaching was also a strong driver to seek support, ultimately leading to the identification of dyscalculia.

Once in HE, the process of seeking support and identification was most often led by the participant. The need to be proactive is most likely a result of the independent nature of learning within HE institutions. With less student-to-teacher contact time than is generally experienced at school or FE, the onus is much more on the student to address their own difficulties. This is likely to be daunting at a time when every student is faced with the challenges of transition to a higher level of academia and possibly independent living. There are no figures available for the number of dyscalculic students who quit or fail HE having not sought learning support.

The label of dyscalculia for most of the participants did not appear to be viewed negatively and one student was proud of her neurodiversity. There were, however, some caveats. Two participants felt angry that identification had taken so long. One student also viewed the label of dyscalculia as potentially negative in her struggle to be accepted within a nursing career. A few participants also felt that they now had an excuse to fail as they could use dyscalculia as a legitimate excuse for avoiding mathematics. Participants’ reactions on being identified with dyscalculia however were overwhelmingly positive and they all described a sense of relief at finally having an explanation for their difficulties.
9 Experiences of mathematics in higher education

9.1 Introduction

This chapter addresses the second research question:

What are the experiences of mathematics of dyscalculic students in HE?

It explores the academic and everyday life mathematical issues faced by dyscalculic HE students, and directly addresses the mathematical issues of dyscalculia, as opposed to the wider affects on societal inclusion, support and well-being. Although I chose not to ask my participants to perform mathematical tasks due to the potential for mathematical anxiety, different types of mathematical difficulty did emerge from their narratives. All the mathematical findings of my study have been collated in a single chapter to allow for a greater depth of analysis of the mathematics difficulties associated with dyscalculia.

The chapter is split into four sections. The first section verifies existing knowledge of the discrepancy model of dyscalculia by examining the extent to which descriptions of known arithmetic difficulties were found in my data. On analysis, this not only supported the identifications of dyscalculia of the participants, but provided real-life contextual examples of how these difficulties can manifest themselves. It then goes on to discuss non-integer representations. This was of particular relevance to HE as most courses use mathematical data in some form and this is likely to be non-integer if it refers to real-life measures. The use of non-integer representations was shown to be particularly problematic for dyscalculic learners.

In the next section I consider the most fundamental quantifying skills such as counting, subitising, and the ability to judge numerosity, which some definitions of dyscalculia refer to as ‘number sense’ (see section 3.8.2). The extraction of these characteristics from the participants’ stories was useful in learning how they occur in real-life academic and everyday scenarios, as opposed to specifically designed assessments or experimental tests. What is clearly evident from the participants’ reflections is that although all students in the study struggled with significant mathematical difficulty, not all the participants had issues with these fundamental mathematical skills. This suggests that not all the participants would be considered dyscalculic under the Butterworth model which considers dyscalculia as a discrete neurodiversity (see section 3.8.1), rather than a spectrum of difficulty where mathematical ability is judged relative to general intelligence (discrepancy model, see section 3.3.1.4). The subset of my sample that fell
into this more tightly defined group was categorised as *dyscalculia with numerosity issues (DWN)* (see section 7.6.1.1).

The third section explores the theme of time. Section 3.6 discusses existing research showing that dealing with time is known to be problematic for dyscalculic individuals. Specific difficulties vary between participants but can be broadly grouped into categories of telling the time, understanding the concept of how time works, time management, punctuality and judging the passage of time. Time management and punctuality were problems that appeared to be particularly relevant in HE, and emerged as a key theme and a barrier to respondents’ social interaction, which is in keeping with what is known about other neurodiversities (Hendrickx, 2010).

The final section explores the applications of mathematics that were most discussed by the participants. With reference to higher education, certain topics of mathematics caused more difficulty than others. This appeared to be due to the frequency with which these mathematical concepts appeared in HE curricula, even in non-STEM (science, technology, engineering and mathematics) subjects. As quantitative methods are increasingly becoming a mandatory component of many undergraduate courses (Porkess, 2011), it was likely that statistics within courses in HE would be a theme to emerge from the research interviews. As summarised by Cerrito (1999), "*statistical literacy is no longer a luxury; it is a necessity*” (p9). The use and understanding of standardised units is also a vital skill in HE and one that all the participants found difficult.

The last part of this section refers specifically to the mathematics encountered within the subject of fitness to practise (see section 5.10). Non-mathematics issues with regard to dyscalculic healthcare students are discussed in chapter 12. The theme of fitness to practise was split in this way to collate the mathematics discussion in a single chapter.

### 9.2 Arithmetic

This section explores the participants’ experiences of arithmetic. This includes the ability to memorise number bonds and multiplication tables, and the use of the four arithmetic operators. I then go on to discuss place value and non-integer representations, such as percentages, fractions and decimals.

#### 9.2.1 Number facts and properties

Although some definitions of dyscalculia include the memorising of number facts as a characteristic (Geary, 1993; Shalev & Gross-Tur, 2001; Department for Education and
Skills (DfES), 2001; Landerl et al., 2004), a co-occurrence of dyscalculia and dyslexia (see section 4.2.1) or severe mathematical anxiety may also affect the ability to remember number facts as they both have a strong correlation with poor working memory (see section 4.4.2). It is therefore difficult to verify whether dyscalculia can cause number fact issues independently as it is difficult to isolate the dyscalculia from other neurodiversity and well-being effects. In this study, students from both the co-occurrence of dyscalculia with dyslexia (CDD) category and the highly anxious (HAnx) group showed evidence of difficulty with remembering number facts which could possibly have been due to the non-dyscalculic reasons mentioned above.

Difficulty with memorising number facts could, however, be grounded purely in dyscalculia. The participants struggled to understand why many number facts were true and therefore found it difficult to forge mathematical cognitive links, increasing the risk that these number facts would be forgotten. Fiona claimed that she couldn’t remember number facts because:

_They don’t stack up in my mind in a useable manner._ (Fiona)

Ellen also described how she was unable to form cognitive links between mathematics and her other subjects:

_There are no connections whatsoever. I always feel maths on that side of my head [touches right side of head], I know that sounds weird. But everything else I understand is on this side, and maths is there on its own, like it’s wandering off_ (Ellen)

The recollection of number facts may therefore not be as secure as it is with neurotypical learners. Gersten and Chard (1999) acknowledged this issue by questioning whether mathematics education of students with mathematical learning difficulties was too often concentrated on the mastery of number facts and algorithms which could deny the learners the opportunity to evolve their own mathematical understanding. Gemma described how her overriding memory of school was practicing number bonds and times tables:

_We used to have mental maths tests where my teacher would read out a string of instructions. So, you know, “Start with fifty seven and times two, times three minus four”... It was terrible and I remember getting those tests back and getting sort of five out of fifty. She [teacher] was really into them... I was struggling to think about the numbers and what I was trying to do to them._ (Gemma)

In addition, neurotypical learners can generally extrapolate new number facts based upon a minimal number of key facts, creating a collection of number strategies (Brownell
& Chazal, 1935). For example, if a neurotypical student knows that two plus four is six they may then be able to recognise that twenty plus forty is sixty. By definition, dyscalculic learners lack this ‘number sense’ and struggle to build number facts upon fundamental number bonds or times tables, and are therefore more reliant upon calculators (see section 10.3.3). This facet is one of the testing components of the DysCalculiUM screener (see section 5.7).

All the participants were able to recall some number facts, even those participants that were the most severely dyscalculic (DWN):

\[
\text{I've always got a little bit of two times table, bit of five, bit of ten and the rest of it, not a bit. (Nancy)}
\]

However, a combination of the above number fact retention issues and the ability to apply these facts meant that mental arithmetic was often both difficult and stressful, as described by Quentin:

\[
\text{If I were to try to do something like, I don't know, 75 take away 28, I would need a pen and paper for that, just because I wouldn't be able to hold on to the value of 75 and then take 28 away from it... I'm focussed on each digit, and then the whole digit, or the whole number, then the subtraction, then coming back to 75 and trying to think, "What was that again?" (Quentin)}
\]

A neurotypical learner in the above example could use the number bond of seven plus eight equals fifteen to recognise that the number after subtraction would end in seven. This would reduce the working memory required to complete the mental arithmetic task. Quentin may struggle for three possible reasons here. Firstly, as a member of the HAnx group, his severe mathematical anxiety could reduce the available working memory to conduct the task, and this was eloquently described by Quentin. Secondly his mathematical anxiety may have prevented him from remembering a helpful number bond such as seven plus eight equals fifteen. Thirdly even if he could recall the number bond of seven plus eight, his may not realise how to apply that information into a useful computational strategy.

Many of the participants reported that through their school experiences much of the teaching put an emphasis on number facts and mental arithmetic.

\[
\text{It was everything [at school], mental arithmetic. I couldn't just work it out it my head like that. People were knowing the answers and I wasn't, and I remember people by the side of me seemed to know what they were doing and getting on with it and I was just stuck. (Deborah)}
\]
Due to a combination of the above effects (summarised in table 14) a dyscalculic student may have little chance of success with number fact learning, thus highlighting at an early age inequality with their peers, mathematically, and potentially affecting self-esteem (see section 11.3.1).

<table>
<thead>
<tr>
<th>Negative effect</th>
<th>Neurodiverse core reason</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory</td>
<td>Dyslexia</td>
<td>Poor working memory prevents number facts entering long term memory</td>
</tr>
<tr>
<td></td>
<td>Mathematical anxiety (linked to dyscalculia)</td>
<td>Lack of mathematical links to number facts prevents them being made secure in memory</td>
</tr>
<tr>
<td>Mathematical links</td>
<td>Dyscalculia</td>
<td>A difficulty in expanding on core number facts to create new number facts</td>
</tr>
</tbody>
</table>

Table 14 – Number fact memorisation factors table

Although number facts are important to help students build up their own layers of understanding and allow them to create their own mathematical strategies, the emphasis on their importance at an early age was such that many participants felt that they were unlikely to succeed:

> It was terrible and I remember getting those tests back and getting five out of, I think they were all out of fifty. I think you knew it was going to go badly, it was almost like there was nothing you could do about it. It was just going to be horrible and you were just going to have to sit through it, and it was preferable just to write random numbers down. (Gemma)

Most of the participants had been made to feel they were poor at mathematics because they had difficulty in remembering number facts, which are not necessarily a predictor of mathematical ability. Boaler (2014, p1) claimed that “many classrooms focus on math facts in unproductive ways, giving students the impression that math facts are the essence of mathematics.” This educational approach disadvantages neurodiverse students with poor memory and does not offer an inclusive and differentiated environment.

### 9.2.2 Four operations

When the participants referred to the four common operations of addition, subtraction, multiplication and division they all described a mechanical process rather than a
mathematical concept for solving real life problems. They rarely described mathematical operations within a real life context. This may not necessarily be a characteristic of dyscalculia and could instead be a result of educational emphasis on procedure, but it does highlight a tendency for the participants to consider mathematical processes as abstract entities. Five of the dyscalculic students referred to the performance of these four operations as "the basics".

\[
I \text{ had no understanding, and I probably did not understand the basic rules of maths.} \\
(Deborah)
\]

This repeated referral to "the basics" suggested that the dyscalculic students viewed the mathematics which they did not comprehend as a discrete entity that had eluded them for educational reasons. It was not until their identification of dyscalculia, and subsequent greater awareness of neurodiversities, that this opinion changed (see section 8.5.4).

Knowing the correct procedure to apply to a given contextual situation was shown to be problematic for the most severely dyscalculic students (SDY), like Rebecca:

\[
To \text{ me, I can see the numbers, but I just don't know how to work it out.} \ (Rebecca)
\]

The participants’ thoughts on the four operations were mostly dependent upon their procedural difficulty without a calculator, which had been formulated through their early education:

\[
I \text{ can add quite well. I can’t divide. I’m not particularly good at timesing \[sic\]. And subtracting is horrendous.} \ (Ellen)
\]

All the participants described viewing mathematical problems as a set of `sums’ where a procedure is followed to produce a correct numerical result. As a consequence, they appeared to judge their mathematical abilities on how well they performed the mechanics of these four operator tasks. Most of the participants were unaware of the existence of arithmetic ‘concepts’ and saw the subject of mathematics as merely a set of obscure procedures used to produce a correct answer:

\[
But \text{ maths is just like an answer… why does there need to be an answer?} \ (Bradley)
\]

Bradley disliked mathematics as he could only view it as a process to determine a single result, and all other results would therefore be without merit. Even though he would need to know exact measurements for working with textiles, he still saw the mathematical process as contrary to his artistic background where there may be many valid solutions to solve a problem of function or aesthetics. He added:
In Art and Design there is no proper conclusion, you can think deeply about things and there is no real solid ‘thing’ there. (Bradley)

The ‘thing’ Bradley refers to is a ‘fixed’ answer. He preferred to work in a way where he was creating something new rather than finding a pre-existing solution. Another possible reason for Bradley’s dislike of mathematics could be his difficulty in utilising his strengths in creativity as a coping strategy for succeeding in mathematics.

The participants’ feelings about mathematics as a mechanical process independent of a wider logic suggested that a possible overemphasis of procedural learning in early years had an impact on how the participants saw themselves as mathematicians. Where a student felt they could perform a specific operational task, they were keen to claim this as a mathematical success, as exemplified by Olivia:

*I’m really good at the theory. I know if you add that number and that number, you will find the area or whatever. I know all the formulas [sic] and I know how to get an answer or what you have got to do with the numbers.* (Olivia)

When some of the participants proudly claimed that they could “do” some particular topic of mathematics, they meant that they had mastered a procedural method that would consistently produce a correct answer, and not that they understood the concepts behind the topic or why the result was correct.

### 9.2.2.1 Addition

The extent to which the participants were able to comprehend a relationship between mathematical operations and real life problems appeared to depend upon the severity of their dyscalculia, but all the participants were able to demonstrate a reasonable understanding of addition.

*Adding I can pretty much cope with. I add on my fingers, do things like that and, again, if it’s more fingers than I’ve got, I have to write it down. I do make silly mistakes all the time.* (Fiona)

The concept of bringing two sets together to create a new larger set was intuitive to all the participants, and they understood that this was known as addition. They were able to use counting strategies where the numbers were not too great, either using their fingers or drawing dots on a piece of paper to represent the scenario and re-counting the total number of dots on completion. The lack of memorised number bonds, as discussed earlier, meant that the addition process was rarely straightforward, but all the participants felt they could correctly calculate ‘small number’ addition given enough time or a calculator.
9.2.2.2 Subtraction

The real life concept of removing items from a set was reasonably well understood by the participants, but the process of achieving this was problematic:

*Subtraction I struggle with as well because if you’ve got that issue...* (Fiona)

Here Fiona was referring to the ‘borrow one’ procedure adopted in the column subtraction method. The concept of ‘borrowing’ was not understood by any of the participants who discussed it. Some of the participants who were not in the DWN group described being able to use the counting-on method to calculate subtractions:

*I’ll count from there to your second number, literally, count by making tally marks on a page, so if I’m taking 58 from 103, I’ll count from 58 up to 103 and then I’ll count those bits between 58 and 103. That’s when I’m really pushed and I have to do it.*

(Fiona)

Fiona did not like performing subtractions because she was aware that her chosen method was slow and prone to error, even though it was mathematically correct. This does follow a common theme throughout the study, where if the participant discovered a method that worked for them, they tended to continue using that method rather than learn a more efficient strategy. Another example of this resistance to change is where several participants were reluctant to change a ‘working’ everyday practice such as using public transport, even if they were aware that their travel method was inefficient (see section 10.2.4). This demonstrates that the participants often had an acute awareness of their difficulties even if they were able to find strategies to overcome them.

9.2.2.3 Multiplication

Most of the participants considered multiplication to be a repeated exercise in addition, rather than a separate operation, as demonstrated by Linda. Despite her severe dyscalculia, Linda was able to perform simple addition, and had recognised that multiplication could be performed correctly by repeated additions, which is already known to be an embryonic multiplication strategy (Chinn & Ashcroft, 2006). She was very proud of this self-discovery which had given her some sense of mathematical achievement:

*I came up with a strategy of how to add multiple numbers... Say I’ve got to times seven and eight, I would write down eight seven times and then add two together and then put the number at the side, then add the next two together and put the number, and then add until the list was complete. And then I would go down the next list, adding those two numbers together until I ended up with one number.* (Linda)
The popularity of this commonly used strategy could be because multiplication was too difficult a concept for the participants to understand, or because they were unwilling to explore a new idea once they had found a method that relied upon an existing skill. For the participant with the most severe dyscalculia (DWN), Maggie, the concept of multiplication was completely elusive:

*I still don’t really understand it [multiplication], what it is for.* (Maggie)

Some of the non-DWN category participants had developed more advanced strategies for multiplication. Fiona was able to describe a mixed strategy using times tables and addition which implied she had a better understanding of multiplication, and had not just retained some number facts around multiplication:

*I know two eights are sixteen and then I have to add another eight.* (Fiona)

It was small arithmetic insights like this that aligned Fiona with the dyscalculia without numerosity issues (DWO) category, rather than the more severely dyscalculic DWN category. One of the few examples of where a participant described a real life scenario of using a mathematical operation was when Deborah performed a stock-take of medicinal tablets. For one tablet, which was stored in packs of ten, Deborah was able to use the ten times table to count them. However another tablet was stored in packs of fourteen, which caused her considerable difficulty. Even though Deborah had a calculator, she would count the pills individually to perform a stock-take. This was because her concept of multiplication was not secure enough to use the calculator and she was unable to remember or use any number facts that were relevant to fourteen:

*Some drugs are, they’re in like packs that you push out the tablets and sometimes they’re in tens, packs of tens which is fine. But if they were in fourteens, and even now if there’s fourteen in a pack I have to count it and count all of them.* (Deborah)

Packaging pills in packs of fourteen did not allow for any simple counting strategies. Had the pills been packaged in tens for example, Deborah would have found this task much easier.

Because Deborah had found a quick method that worked for boxes of ten tablets, she was aware that her counting method for other boxes was inefficient and that the task could be performed more quickly by other nurses. This led to a peer comparison affecting her sense of identity as a nurse (see section 11.3.1).
9.2.2.4 Division

Division was the operation discussed most by the participants as it was both the operation with the least meaning, and the most difficult from a procedural perspective. A few of the participants had some sense that division was a way of sharing a resource between people, which is known as the partitive model of division (Ball, 1988). No other concepts of division were described. With the division operator, the moderately dyscalculic participants (MDY) did not demonstrate a level of understanding any greater than the severely dyscalculic participants (SDY):

Say you’ve got a piece of cake and you’ve got six people, you divide your six into the whole, so you are divvying [sic] something up, but that’s about the level I get to. Don’t ask me to do anything more complicated than that and I struggle. (Fiona)

Alison was the only participant to discuss a strategy for performing division. She was able to appreciate the need to share a resource, and gave an example of handing out sweets. Her chosen strategy was the method known as ‘direct counting’ (Mulligan & Mitchelmore, 1997) where she would give one sweet to each person until they ran out, and then judge the final distribute of sweets by counting each share, to decide whether the distribution had been fair:

The only way I’d understand it was if they had the sweets in front of us, actually divided the class up into the children ”Now what are you going to do?” So then you go round and see what you’ve got to give each person, but obviously you can’t do that each and every time you have to do the sums. (Alison)

As Alison had a co-occurrence of dyslexia, she was better able to understand the complexities involved if she could experience the problem within a visual context. She therefore found it much easier to comprehend the division task when faced with tangible objects such as sweets. The use of representative kinaesthetic objects, known as manipulatives, to aid dyslexic and dyscalculic learners’ mathematical understanding is discussed in section 10.4.4. In a similar way to Deborah’s counting of tablets previously, she understood that her method was not efficient, but failed to understand how a better strategy could work. She was aware that there was a procedural method for calculating division, but was not confident in its use:

So most of the time I just knew that the bigger number went on the top or that it was a smaller one or whichever one it was, usually the bigger one and then the smaller one underneath. But I never knew because "Oh, you wanted to share it out between
Maggie, the most severely dyscalculic student in my study, had no concept of division at all and no strategies for sharing a resource equally. When asked how she would share a chocolate bar between friends she replied:

"Normally I just break it up randomly. Does that count? If it looks the same, I guess it's the same. Yeah. I would just snap it." (Maggie)

For Maggie there was some sense that each shared portion needed to be the same size, but she had no strategy for achieving this. She was however able to use a post-division visual method to check whether she would be sharing the chocolate equally, which maybe be indicative of a dyslexia-related visual acuity.

Gemma, as one of the high achievers (H Ach), was the most confident in terms of division as a mathematical concept, but she still struggled with the operation from a procedural perspective due to the number of methods she had been taught in the past:

"I'd learned, in the end, about five different methods to divide... I just couldn't do them, and I would just end up entirely lost, or come out with a completely wrong answer. So then I was sort of getting mixed up between methods, as well." (Gemma)

As a result of the conceptual and procedural difficulties, all the participants had a strong dislike of division and avoided tasks that involved this operation whenever possible.

### 9.2.3 Place value

A sound understanding of place value is one of the prerequisites for mathematical success (National Research Council, 2009) and is crucial for being able to read numbers correctly and to compare values in Arabic numerical representations. Without this understanding, numbers are individual discrete elements that bear no relationship to each other and have to be uniquely remembered where they occur in a sequential list. Difficulty with place value was specifically described by two of the three students in the DWN group, who I consider to be the most severely dyscalculic participants in my study. Maggie had learned how to read numbers with three digits, but struggled with four:

"I can read the number one thousand, and after that I start getting confused." (Maggie)

When I showed her a four digit number, ‘2287’, she was unable to recognise the meaning of the initial thousands digit, and how that affected the numerical size of the number.

"Is it something like two hundred and eighty seven but not?" (Maggie)
Linda was able to read four digit numbers, but struggled to understand how subsequent digits beyond the first could be used to determine comparative size:

If they [two numbers] were 1000-and-such-and-such and the other one was 1000, I would struggle with that. If it was in the 1000s and the 2000s, I would be ok because I would look at the first number. (Linda)

Both Maggie and Linda have an insecure sense of number, and how numbers combine to create larger numbers. They had some sense of comparative size for numbers with three digits, but this could be through prior experience of using those numbers rather than an understanding of the mechanics of place value. All numbers of four digits or greater would be considered ‘large’. If one number had noticeably more digits than another, then they might sense that that was a greater number because it looked bigger. The two participants were self aware that numbers of four digits or greater were problematic. This had led to extensive avoidance strategies, particularly where information could be obtained from other sources, such as text or pictures, rather than from numerical data (see section 10.2.3).

Difficulties with place value may not only be a result of a lack of understanding of the mechanism involved, but also due to problems with subitising as discussed in section 9.3.3. When Linda was asked whether she would recognise that a number with fewer digits would be smaller than a number with more digits, she stated that she would not:

It’s not something that I would pick up on at first glance. I could sit there and count the digits, but just from looking, I wouldn’t notice that. (Linda)

This shows that subitising difficulties are not an isolated dyscalculic characteristic, but a contributing causal factor that explains why some elementary mathematical concepts can be difficult for a dyscalculic learner to comprehend.

9.2.4 Non-integer representations

Difficulty with integer numbers is a defining characteristic of all models of dyscalculia as detailed in section 3.5, and all participants described difficulties with this throughout their lives. On entering HE, however, most participants reported that it was the need to understand non-integer numbers that presented the greatest challenge. This section explores how the participants interpreted non-integers and the factors affecting their confidence with representations such as decimals, fractions and percentages.
9.2.4.1 Percentages

All participants in the study described some difficulty with interpreting percentages although many reported a greater level of comfort with percentages than other non-integer representations. Despite the fact that the percentage format employs an abstract ‘%’ symbol, participants reported less confusion with percentages than with a decimal point or the numerator, denominator and division line of a fraction. This may be because percentages are generally expressed as ‘whole numbers’ rather than including a decimal point.

It was notable during interviews that several participants used percentage terms within their everyday language. For example, Alison often showed agreement by replying "100% correct" regardless of whether the topic of conversation was mathematics related. It was my impression that this was not related to a comprehensive understanding of percentages, but it was interesting that the language did not provoke the same anxiety as other mathematical terminology.

The majority of students across all groups were able to display some understanding of percentages related to academic assessment, and were aware that a larger number meant a higher degree of achievement, as illustrated by Heather.

*I got something like eighty percent or something, I did really well.* (Heather)

Whilst many of the students described a reasonable degree of comfort with percentages, it was clear on further discussion that this confidence was related only to the academic scale of ‘correctness’, as a measure of success. There was no evidence that any student had an understanding of the concept of a percentage being a portion of a whole and none were able to demonstrate an understanding of percentages outside academic assessment scales, or the ability to manipulate them within calculations, as typified by Rebecca:

*If I went into a shop and it said, “60 or 50 percent off”? I wouldn’t have a clue.*

(Rebecca)

The participants’ confidence with percentages in the context of academic achievement may be related to the familiarity of the format and their ability to relate it to real world experiences. This contextualisation can make concepts seem less abstract and consequentially make them more accessible to dyscalculic learners and this is explored in detail in section 10.4.4.
Students in the *dyscalculia with numerosities issues* (*DWN*) group were less able to comprehend the concept of a uniform scale which is unsurprising, as the creation of logarithmic internalised number lines is a well established characteristic of this group (see section 3.8.2).

### 9.2.4.2 Fractions

It is well established that fractions can be difficult to interpret for both neurodiverse and neurotypical learners (Behr et al., 1984; Hope & Owens, 1986; Chinn & Ashcroft, 2006). All the participants in my study expressed a dislike of fractions and a lack of comfort in using them. Piaget (1987) claimed that the understanding of fractions involves two connected aspects: multiplicative reasoning and conservation of the whole and the constituent parts. The comprehension of fractions is built upon the foundations of more fundamental mathematical concepts. All participants in the *severely dyscalculic* (*SDY*) group in particular, struggled to conceptualise the meaning of a fraction, although they were familiar with terms such as "half" and "quarter" and could understand they represented a smaller amount than a whole. For example, when Maggie was asked what a fraction was, she stated:

> I know a half is like... [waves hand in the air in a chopping motion] Like that. That's all I know. (Maggie)

Maggie was able to describe a half as one of two parts of a whole, but it was unclear that she understood that two halves had to be equal in size. As demonstrated in section 9.2.2.4, this fundamental lack of understanding meant that Maggie had no strategies for dividing an object equally.

Participants in the *co-occurrence of dyscalculia and dyslexia* (*CDD*) group described a better understanding of fractions than those in the *dyscalculia only* (*DYO*) group, frequently citing the benefits of learning aids such as manipulatives and diagrams. These resources complimented the strong visual skills of dyslexic students (see section 4.3.1) as demonstrated by Alison, who described an occasion when her private tutor baked a cake with her as a way of supporting her understanding of fractions. Not only did this provide an in-situ contextualised environment for the use of fractions that has been shown to be helpful to dyscalculic learners (see section 10.4.4), but also offered a positive learning environment through imagery, touch, taste and smell. This multisensory learning, which is already known to be beneficial to dyslexic students, was well-evaluated by Alison. As a participant within the *CDD* group, she gave examples of strong visual memory skills which she was able to use to recall the baking exercise and improve the likelihood of her retaining the knowledge. For *DYO* students, however, or those
without strong visual skills, visual or tangible resources were not as helpful. This was exemplified by Heather talking about her seminar on how to teach fractions to early years children:

Don't talk to me about fractions. We've had fractions seminars this week... they [teachers] give you the multi-link blocks and things, it does not help me at all. I've never been able to grasp it. (Heather)

Heather expressed that the use of these manipulatives had failed to give her a better understanding of fractions. For a dyscalculic student with dyslexia, or a dyscalculic student who prefers a multi-sensory form of learning, a strategy of learning using manipulatives may be successful. For a purely dyscalculic learner such as Heather, however, the multilink blocks had no context, and were perceived as abstract objects. It may have been difficult for her to contemplate how the separate blocks form a whole, as there was no recognisable contextualised ‘whole’ to begin with. The blocks may also have been disliked as they were considered to be ‘mathematical’ objects which then led to mathematical anxiety. This idea was reinforced when in contrast she remarked that the use of a chocolate bar had made an impression on her as a means of understanding fractions:

I just could not see it [fractions]. But then she [lecturer] did it with a chocolate bar and I could see it with the chocolate bar. I don't know why. It was because it was a Kit Kat and you could split it up. (Heather)

The introduction of a recognisable object which had meaning in Heather’s everyday life gave the scenario a more real context and supported her learning.

Students in the high achievers (H Ach) group had more success in answering questions involving fractions than other participants, as described by Gemma:

As part of this maths course we did last year we did a lot of fractions and I now feel confident manipulating fractions, like I can times them together, I can add them together and find the common denominator and the like, but I don't feel like I'm getting any real information from them. (Gemma)

Although Gemma struggled with the concept of fractions, she was still able to use them within her assignments by following an algorithm. This may be down to well-developed procedural skills, which are discussed in section 10.2.1.
9.2.4.3 Decimals

From a semiotic perspective, the decimal point is one of the first mathematical representations that advances the learner beyond the simplicity of whole numbers encountered in the everyday world. It is well established that decimals can be problematic for neurotypical learners with low numeracy skills (Ni & Ni, 2010). Examples of common misconceptions include assumption that the number of digits after the decimal point indicates numerical size, or the insertion of a zero after the decimal point to multiply by ten (Steinle, 2004).

All participants in the SDY group had previously described some difficulty with comprehending place value as discussed in section 9.2.3, and these difficulties also apply to the concept of value in decimal places. They frequently stated that they struggled to understand decimals and their associated number properties as illustrated by Olivia:

_I've really got no concept of if you multiply by a decimal, for example, which way the number is going to go. So, if you multiply five hundred by nought point two five, I don't know whether that's going to come out bigger or smaller than five hundred._ (Olivia)

Students in the HAch group exhibited the most competence in the use of decimals, but expressed that this was from a procedural perspective rather than a sound conceptual understanding. The only other participants who showed some confidence with decimals were students in the CDD group, when describing the physical use of money. Of this category, Ellen was the most comfortable, describing a strong disparity between her difficulty with decimal mathematics and her comfortable use of decimals in monetary terms:

_If you gave me a number with a decimal, I would die. But if it's got that pound sign there, it’s acceptable._ (Ellen)

This suggests that context is crucial to help with the understanding of mathematical concepts. In addition, as discussed in section 10.2.3, dyslexic learners are more likely to prefer a visual or practical format when dealing with concepts related to mathematics. It is possible then, that this is an explanation for why students in the CDD group were more able to cope with money, despite difficulties with decimals as an abstract concept. Money can be seen and handled as notes and coins in very practical terms, which the dyslexic students found more accessible.
9.3 Number sense

This section concentrates on the concept of ‘number sense’ (see section 3.8.2) and the inherent mathematical skills of understanding the meaning of ‘number’. Difficulties with these fundamental mathematical skills form the basis of the alternative Butterworth model of dyscalculia (see section 3.8.1). I have also chosen to focus on two additional concepts of fundamental difficulty: the comprehension of non-integers and non-cardinality, which emerged from my data as possible explanations for particular issues in the application of mathematics.

9.3.1 Counting

Difficulty in counting is one example of a fundamental number sense issue that is indicative of dyscalculia (see section 3.5). This can incorporate not only sequential counting, but also counting backwards or in intervals greater than one. Seven participants described difficulty with counting, even when using fingers as a coping strategy. The most severely affected was Linda:

*I can count probably to about twenty and then, after that I stumble with the numbers.
Then, maybe I'll get up to thirty and I'll jump straight to forty. Or I'll go, "twenty-nine, thirty-two" or something like that. I'll jump numbers and I miss huge sections out with numbers.* (Linda)

Although Linda was aware that her counting mechanism was unreliable, she was unable to find a coping strategy to counteract this. She was one of two participants who had major difficulty counting forward from a two digit number. This was acutely embarrassing to her, and a task she would avoid if at all possible. Maggie also had significant difficulties with single increment counting:

*When I was counting, I knew the words for it, but I didn't say them like everyone else did, if that makes sense - like I got them the wrong way [round].* (Maggie)

This difficulty encountered by the most severely dyscalculic students (DWN category), suggests that counting is an exercise that goes beyond remembering a sequence of number words, and is rooted in a conceptual understanding of a number system. When neurotypical individuals count they initially recite values from rehearsed memory, but at various points in the process a conscious decision is made to determine the next number which is based upon mathematical understanding (Logie et al., 1994). This explains how counting in steps greater than one or counting backwards appeared to cause severe problems for the dyscalculic students as those number sequences may not have been
recorded in memory. Counting in steps of two was therefore more commonly described as a problem across all the dyscalculic categories:

*That's impossible if it goes higher than twos I can't do it, it's really difficult. (Bradley)*

Adding the value of identical coins is an example of counting in larger intervals. When Rebecca worked part time at the university cafe she was sometimes tasked with cashing up the tills, a job that she dreaded:

*I would literally dread it, because it means having to count it up. And like with 10 ps, you've got 10, 20, 30, 40, 50, 60, 70, 80, 90, and with 5ps I would have to go, "5, 10, 15, 20, 25, 30..." I can't remember them. I had to write everything down. I had to have little bits of paper saying, "That's £1 or £2" if it was all in loose change. I had to do it that way, because there was just no way of doing it. It was horrendous.*

(Rebecca)

For Rebecca, there were too many simultaneous difficult tasks. Not only did she have to concentrate on counting in non-unitary intervals, she then had to store the values of each pile of coins to working memory, which may have been compromised due to her mathematical anxiety. Handling money was a commonly discussed task amongst the participants that required counting skills, although with the advent of debit cards as a coping strategy this particular scenario is less common in everyday life than it may have been previously.

### 9.3.2 Numerosity

Recent definitions of dyscalculia concentrate on numerosity as one of the major characteristics (see section 3.3.1.2). All the participants described some form of numerosity difficulty, but there were three participants who appeared to struggle significantly more than the others, and were allocated to the *dyscalculia with numerosity issues* category (*DWN*) (see section 7.6.1.1). These were the participants who struggled to perceive number size and compare numbers without any visual stimulus, as described by Nancy:

*When you get into large numbers or quantities or distances, or anything like that, I can’t conceptualise it unless I’m shown it in some way. It’s got to be visualised.*

(Nancy)

All participants in the study were able to perceive one quantity as greater than another if they could experience it either visually or tangibly, such as having to recognise which bar was taller on a bar chart. Difficulty arose when they had to estimate number size based upon their own internally constructed mental number line. As described in section 3.8.2,
the malformation of this number line leads to highly inaccurate size comparisons, referred to as numerosity issues. Unlike with counting as discussed above, the internal mental number line as described by Dehaene (1999) cannot be constructed through phonic rehearsal and must be accessible at any point along its length. Also, counting only indicates sequence and an ordering of values. The internal mental number line has to provide a means to estimate comparative distances (Dehaene, 2003).

The participants struggled to estimate size when the number was associated with a standardised unit. This was not necessarily an effect of numerosity, but could also be linked with other dyscalculic characteristics. The difficulties with standardised units are discussed in section 9.5.1.

9.3.3 Subitising

Subitising is the ability to recognise the cardinality of small numbers of objects without counting. Researchers such as Butterworth (1999) believe this to be a crucial characteristic for identifying dyscalculia (see section 3.8.1). Assessment of the ability to subitise correctly forms part of many dyscalculia screeners, including DysCalculiUM (Tribal, 2010) and the Butterworth screener. Although my research did not specifically aim to test or question the participants regarding subitising, there was some evidence of subitising in my study. Three of the participants described difficulty in recognising the number of digits in a two, three or four digit number without counting. Subitising difficulties were not only experienced by the DWN group, but were described by participants who did not struggle with severe numerosity issues, as would be consistent with the Butterworth model. This is logical as subitising and approximate number estimation are associated with different parts of the brain (Piazza et al., 2002).

As my categorisation of dyscalculia is based upon the profile with which each participant is most aligned, a number of participants showed some characteristics applicable to more than one category. Fiona, for example, described a number of mathematical strategies that suggested she was not one of the most severely affected participants, but she found subitising an issue when trying to read a number ending with zeros:

_A row of zeros, I cannot count them. I can’t distinguish between two, three and four zeros. Even two zeros, I have to count them. I have to put a finger on it and count them._ (Fiona)

To correctly recognise a number ending in zeroes, the exact number of zeroes must be determined. For numbers where the number of zeroes was less than six, e.g. 10, 100, 1000, 10000, a neurotypical individual could typically establish the number of zeroes
without the need to count. However a learner with subitising issues like Fiona, would have to count each zero to establish the number. Fiona was able to find a coping strategy for subitising difficulties by using patterns. When objects are placed into recognisable organised patterns, neurotypical individuals can subitise greater numbers than would be possible with randomly distributed objects. For example a six on a dice is instantly recognisable (Chinn & Ashcroft, 2004), whereas six random dots would be difficult to subitise.

*I’ll put marks on a page and if it’s a 5, I’ll put it in the standard dice formation of a five.* (Fiona)

Unlike Fiona, Linda did not find pattern recognition a helpful way of countering subitising issues. When Linda played mahjong, a Chinese board game, she struggled to recognise the identity of tiles by their corresponding object patterns, and was forced to count the objects on the tile each time:

*But it’s the circles and the bamboo that I struggle with. I’ll see a six and I’ll be looking for another six, but I keep hitting the five and the four as well.* (Linda)

The strategy of pattern recognition that was helpful to Fiona was not successful for Linda. As neither participant had a co-occurrence of dyslexia, the differing results on pattern recognition were unlikely to have been influenced by a dyslexia-related visualisation learning style.

Ellen too struggled with subitising in terms of instant recognition of the number of fingers used when counting:

*And sometimes, if I went like that [shows fingers on hand], I would still have to work it out again... Even though I know I’ve got five digits on each hand, I still get confused.* (Ellen)

When Ellen was using her fingers to keep tally, she was unable to recognise the number of fingers she had raised without counting them individually. A neurotypical individual would instantly recognise the number of fingers showing either through subitising or pattern recognition. It is possible that this could be some form of finger agnosia which is a rare condition that has been associated with dyscalculia (Gerstmann, 1940). Subitising from a dyscalculia assessment standpoint is usually associated with screening using computerised dot recognition tests. These examples show how subitising difficulties are relevant to real life mathematical processing and compromise accuracy.
9.3.4 Comprehension of non-integer numbers

This refers to how a mathematical learner perceives numbers that are not whole. It is to be expected that any learner will find the use of non-integers more difficult than integers as they have to understand the meaning of the decimal point and the decimal place value system, and this is certainly true for dyscalculic learners (Mazzocco, 2008). However, even where a neurotypical mathematics student struggled with the mechanics of using non-integers, there is an expectation that they understand the concept that not all numbers are whole and that numbers can be used to classify objects that are ‘incomplete’. This section explores the idea that some of the most severely dyscalculic individuals are unable to comprehend a number that does not refer to a whole object. Three of the participants in the SDY group described significant problems in comprehending non-integer numbers. Maggie demonstrated the most profound difficulties, being unable to comprehend the existence of a value between integers. When Maggie was shown a ruler and asked to identify an interval that represented ‘1.2 cm’ she replied:

*If you are measuring and it lands here [pointing to 1cm], I would probably just say it was one... Because it's past one, I just go "one". And then if it was past two, I would just say "two".* (Maggie)

On further discussion it became clear this was not a difficulty with rounding, but a lack of understanding of what the intervals between integers represent. When I asked why someone might put the interval marks on a ruler she replied:

*Because they are cleverer than me?* (Maggie)

Maggie appeared to have no concept of what the intervals on the ruler represented because she could not conceive of any type of number existing between integers. She referred to integers as “proper counting numbers”, alluding to a distrust of non-integer numbers because she could not relate them to her real life experiences. This characteristic may also exist with another DWN participant. Linda described having some ability to use place value with reference to money, but was otherwise confused by a decimal point. She went on to say:

*I struggle to grasp the concept of what’s going on.* (Linda)

Unfortunately I didn’t pursue a line of questioning to expand upon this as I had initially assumed she was referring to a difficulty with place value, but on reflection this could be evidence of the same lack of non-integer comprehension exhibited by Maggie. When
initially creating an interview schedule for this study, I included questions about how participants cope with non-integer number representations such as fractions and decimals (see appendix E). At that stage I had not considered the possibility that a dyscalculic student may have no comprehension of non-integer numbers. The findings of the study however, suggest that this may be a feature of dyscalculia and this requires further research.

Whilst the other students in the SDY group had some understanding of the existence of non-integers, none of them showed any awareness that decimals, fractions and percentages are different representations of the same value:

I remember some of the stuff we had to do on the course was converting a fraction to a decimal. I hadn’t got a clue. I mean, I know there is something you are supposed to do with it and I know there’s a formula but I don’t know. (Fiona)

The moderately dyscalculic (MDY) participants demonstrated a better comprehension of non-integers and were able to recognise that there was a relationship between representations, as shown by Gemma:

If someone says zero point two five, I know what that number sort of means. When someone says a quarter, I find it far more difficult to get any actual meaning out of that. (Gemma)

Although Gemma said she struggled with the fractions format, she was aware that both decimals and fractions were different representations of the same real numbers.

9.3.5 Non-cardinality

The term cardinality is used by mathematicians to denote the number of items in a set, and is synonymous with the term ‘numerosity’ used by mathematics cognitive researchers (Butterworth, 2005a). Butterworth (1999) claimed that cardinality is the most natural way for individuals to conceive numbers, as research has shown infants and many animals are able to compare cardinalities inherently through visual and audio senses (Gallistel & Gelman, 2000). For example, Wynn (1992) devised an experiment where a five month old baby was shown three puppets, a screen was raised, and a puppet was removed. When the screen was dropped, the baby demonstrated expressions of surprise. Through repeated testing he was able to deduce that the baby had recognised that the cardinality of the set of objects had been reduced by one (Wynn, 1992).
Numbers can be utilised in other ways however where the number does not refer to the quantity of a set of objects, and I have created the term ‘non-cardinality’ to describe these alternative uses. A common non-cardinal use of numbers is for labelling (nominal numbers), for example barcodes or bus routes, and none of the participants described a difficulty when numbers are used in this manner. However there does appear to be an issue where numbers are used to give objects a value, and that value is not indicative of a visible quantity, for example the purchase price of an item for sale. To illustrate this I have chosen the analogy of snooker balls, which was raised by Green (2013) as an issue for one of her dyscalculic students. In snooker, each ball has a different points value when potted, and that value is determined by its colour. For example a red ball has a value of one point and the blue ball has a value of five points (see figure 19).

A neurotypical individual may have little difficulty viewing the balls in terms of an assigned value, but for a dyscalculic person this may appear abstract and contrary to the natural tendency to consider the snooker balls in terms of their frequency, or size comparison if the balls were different in scale. In a game of snooker a dyscalculic player may deem the red balls more valuable as there are more of them on the table. None of the participants referred to snooker, but Fiona did mention her inability to score at darts which may have been in part due to this effect as well as mental arithmetic difficulties.

The ability to recognise a numerical value, such as the points value of a snooker ball, when it is not associated with numerosity-based data such as frequency or size, resembles the Stroop effect (see section 2.3.5) in that the individual is confused by misleading visual clues. In the absence of numerosity-based data to determine the value of an object, socio-cultural references may be needed to provide the required information. In the snooker example above, some knowledge of the game is required to

![Figure 19 – Example of non-cardinality using snooker balls](image-url)
recognise the differing values of the balls. An understanding of the socio-cultural context as well as the ability to interpret non-cardinal number information is therefore necessary for full participation in the game. Dyscalculic individuals with non-cardinality difficulties may therefore experience social exclusion in a variety of contexts.

The most frequently cited example of non-cardinality issues in my study was with the pricing of retail goods. Non-cardinality in the context of money was identified as particularly problematic as items are given a monetary value which is independent of the experiential properties of the item. For example, in figure 20, both the Stroop effect and non-cardinality may impact on a dyscalculic individual’s view of the value of the two objects; a pineapple may be seen to have a greater value than a mobile phone because in observable ways, height and weight, its numerosity is bigger which is a variation on the Stroop effect. However contrary to the visual clues, neurotypical individuals would assign the higher price to the phone as they would recognise it has a greater commercial value. From the perspective of cardinality, they are equal because they both have a set size of one.

Figure 20 – Example of non-cardinality of object values

Evidence of difficulties with non-cardinality emerged most strongly from the students within the dyscalculia with numerosity issues (DWN) group, although it did appear to be an issue for participants across all categories:

_I can look at spending £10 a week in Starbucks on the same level as spending £115 on a box set of DVDs and it doesn't feel like there's any difference._ (Linda)

Linda’s lack of differentiation between low-value and high-value items could stem from an issue with non-cardinality. Whilst she was able to recognise that £115 is a larger
amount of money than £10, at the time of shopping she was unable to look at the two items with no price indicators and assign a relative value to them. It was only through reflecting on her shopping experiences she was able to have some awareness that she struggled to perceive the socio-cultural monetary value of an item. Labels on the products may have been helpful to Linda to overcome non-cardinality issues, although other issues such as the ability to read numbers could then become a problem. It is plausible that the modern tendency to label shelves rather than individual items deprives a dyscalculic individual of another clue as to the object’s value once the item has left the shelf.

9.4 Time

This section explores the theme of time (see section 3.6). All the participants cited problems with time as a significant issue in their lives, and this section examines different aspects of understanding and using time, and the possible consequences of these difficulties.

9.4.1 Telling the time

All participants described difficulties telling the time during childhood and these experiences were often the first recollections from the participants that they were in some way different to their peers when it came to understanding numbers. This frequently led to negative feelings of embarrassment and frustration, as typified by Quentin:

My Gran said that she was going to get me one [digital watch] if I could learn to tell the time. But because I hadn’t, I wasn’t going to get one. So, there was a punitive thing going on there. (Quentin)

Quentin explained that his family had assumed his difficulties with telling the time must be due to laziness, for which he felt punished as he was unable to achieve the learning goals necessary for the offered reward.

A key theme to emerge was confusion around both analogue and digital time formats as they use differing mathematical skills and the opinions of the participants varied. Although analogue time is taught earlier in the UK educational system than digital time, previous research has shown that both dyscalculic and neurotypical children prefer to read time in a digital format (Friedman & Laycock, 1989).

There were three participants, all within the DWN group, who described a lack of confidence with telling time in any format which persisted into adulthood. Of these,
Maggie had experienced the most severe difficulties. She struggled to understand the convention of referring to times after half past the hour as ‘minutes to the hour’ and was unable to use usual terminology for reporting the time. From memory, she could associate the number three on the clock face with “quarter past” but struggled beyond that:

*I know it [analogue time] until it goes past six, and then I get confused and I choose to ignore it.* (Maggie)

When asked to report the time on an analogue clock, which she described as “*the round ones*”, she used the phrase “*thirty past*” which, whilst mathematically correct, suggests that she struggled to use the socio-cultural conventions of telling the time.

The ability to tell the time from analogue clocks requires three mathematical processes: procedural knowledge, number fact retrieval and spatial awareness (Burny et al., 2012). Although dyscalculic individuals may be able to follow sequential procedures as this has been shown to be their preferred learning style (see sections 3.5 & 10.2.1), the ability to remember time-related number facts may be compromised by the inhibition of working memory due to mathematical anxiety. Some number facts could be particularly difficult to remember due to the Stroop effect (see section 2.3.5). This is where contradictory cues can affect the reader’s ability to extract the relevant information, such as seeing the word ‘red’ written in the colour green. Butterworth (2003) used the Stroop effect to help identify dyscalculic children by showing them numerals, in various font sizes, conflicting with their value. The hour numbers on the clock face represent a different and contradictory set of numbers dependent on which hand is being referenced, e.g. the number three refers to fifteen when indicated by the minute hand. Spatial awareness is required to judge the relationship of the hands to the clock face, and to be able to mentally visualise alternative clock faces when adding or subtracting time. It may also require a spatial understanding of clockwise movements. The relationship between dyscalculia and spatial awareness, however, is still not well understood (see section 3.5).

Participants in the *co-occurrence of dyscalculia and dyslexia (CDD)* group were more likely to prefer an analogue clock, frequently citing a preference for a visual representation of time on a clock face. Although they could still use the normal number conventions of describing the time, for example ‘twenty to three’, these participants were more inclined to tell the time by the shape that the hands made on the clock face rather than referring to the numbers, as described by Alison:

*I don’t look at it as numbers... just kind of shapes.* (Alison)
The CDD participants including Alison had used their dyslexia-related visual memory skills to associate shapes made by the hands of the clock with times, rather than think about the numbers themselves. The size of the sectors formed by the hands, and their orientation can be mentally compared with a stored repository of images assigned to times, utilising this category’s participants’ strong visual memory skills. This may be a common approach with some neurotypical individuals who prefer to learn visually, but for a dyscalculic individual it could help to avoid the anxiety that can be caused by dealing with numbers. Linda was the one exception being a dyscalculia only (DYO) participant who also preferred to use the shape of the hands to tell the time, although she described it as reading “the general time”. Linda found the presence of too many numbers to be stressful, preferring just ‘12’, ‘3’, ‘6’ and ‘9’ to be marked. Although she felt she was “terrible” at telling the time, she had greater confidence using an analogue clock face:

*I’m ok with a clock face, but I’m better if there are no numbers on it... I get confused by the numbers sometimes. (Linda)*

Linda did not have the same inherent visual memory skills as the participants in the CDD group, but described a similar pattern of learning as Julie in 10.2.3 where visual stress, as described in section 4.5, had forced her to adopt a more visual style of learning. Although Linda did not have an official identification of visual stress, she reported that numbers became blurred and difficult to read, which could be indicative of this trait:

*It's almost like I can't focus on them and that confuses me. (Linda)*

The remaining participants in the DYO group preferred numerals to be shown at each hour on a clock face. They frequently reported a struggle to assign numbers to the intermediate interval marks when they were absent. This is another example of the difficulties in interpreting the value of an unlabelled interval, as described in discussion around graphical axes (see section 9.5.2.3). They also strongly favoured a digital format. They did not share the same visual memory skills of the CDD group and struggled to tell the time by the numbers indicated by the hands. Eight of the nine participants in this group expressed a strong preference for digital time, although the 24-hour format was unpopular. Conversion of the numbers of a 24-hour clock to the more often-used AM and PM format is well established as a source of difficulty for many people, including neurotypical individuals (Harris, 2008). It is unsurprising therefore, that it presented problems for dyscalculic learners. Four of the participants in the DYO group specifically mentioned struggling with this representation, as typified by Julie:
24-hour clocks are a bit iffy. I have to work back... the only number I know on the 24-hour clock is 14. I know it’s two o’clock, so I have to work forwards or back, which is really silly. (Julie)

This is an effective strategy which from my experience is commonly used by neurotypical individuals. As a high achiever (H Ach) with better coping strategies than the participants in other groups, and either through observing others or her own realisation Julie was able to find a strategy that worked for her. She was unhappy however as she felt her strategy was clumsy and time-consuming. Where other participants were more likely to be happy with a working strategy, as a participant in the H Ach group she was embarrassed that she continually found difficulty in what she perceived to be a routine task.

As discussed in section 7.6.1.5, participants in the CDD group often have strong visual skills which can lead to different learning styles from DYO students. The findings of this study with regard to telling the time seem to support this theory. The CDD participants described a preference for a more visual learning approach using shapes made by the clock hands while the DYO students preferred the fixed-format numerals of the digital system. Both these strategies were procedural with the participants showing little understanding of the nature of time and how the astronomical time system works. This difference in learning preference between students in each dyscalculia profile category could have significant implications for the support of dyscalculic students when learning to tell the time and suggests the need for time-related resources and teaching methods to be better matched to the preferred learning style of the student.

### 9.4.2 Concept of time

Participants with an alignment towards the dyscalculia with numerosity issues (DWN) category not only described the most severe difficulties with time, but frequently cited examples of more fundamental difficulties than an inability to tell the time or perform time-based calculations. Maggie described the difficulties she experienced in understanding her running times as an athlete.

*I might be able to see the winner, but if it was just from the times, I wouldn't know which number meant the winner and which number meant the loser.* (Maggie)

On further discussion it became apparent that she was unable to comprehend that a smaller time value would represent a faster race when taking part in the 100 metres race. Mathematically this would represent an inverse, and was beyond Maggie’s conceptual understanding. Maggie appeared to always expect a positive correlation.
between number data and desirability, such as in her other sporting domain of football where she recognised that scoring more goals was a better outcome. Maggie did not appear to judge her athletic races in terms of time, but as distance travelled as she could perceive this visually as something that was changing. Buetti and Walsh (2009) observed that fMRI imaging studies, as discussed in appendix M, consistently demonstrate that time-based and number-based tasks activate overlapping regions in the brain within the parietal cortex, which suggests that cognitive time processing could be affected by the same fundamental issues that cause a lack of number sense (section 3.8.2). Buetti argued from a medical model perspective that if the ‘defective’ region of the brain used to estimate numerosity and count objects was the same region responsible for processing time, then analogous results may be seen in the two systems. This appeared to be the case with Maggie as a member of the DWN category. She described severe issues with the perception of time, as well as her difficulties with judging quantities. Section 9.4.5 discusses the poor perception of time as a characteristic of dyscalculia.

Another possible reason for why some dyscalculic individuals described difficulties with time could be that these participants struggled conceptually as they were unable to directly experience time using their senses; although clocks are real-life objects to be viewed or heard, they are only tools for measuring time, which is otherwise ‘intangible’ (Elias, 2007). This is consistent with the way that dyscalculic learners often dislike abstraction and prefer to learn in concrete experiential environments, as discussed in section 10.2.2.

9.4.3 Time management

Effective time management depends on mathematical skills, to assess expected duration of activities and to plan appropriate start and end times. For example the subtraction operation is required to calculate an interval between two times, and addition is used to find a finish time if a start time and duration are known. Time calculations unsurprisingly were found to be difficult due to the non base ten structure of sixty minutes in an hour, as described by Ellen:

_It doesn’t help that there are sixty minutes in an hour. What a ridiculous number. It’s just not a normal number._ (Ellen)

Rounding and estimation are also useful skills to get approximations for time data. An inability to judge the time needed for everyday activities can have a significant impact on the daily life of a neurodiverse individual (Trott, 2003). Twelve of the participants described incidences of being unable to perform this type of calculation. Linda gave an
example from working part-time as a hairdresser while supporting herself in HE. She was responsible for making bookings in the salon:

*It would take me a little bit longer at reception when someone asked... you would have half an hour for a cut-and-blow-dry, whereas if someone was having a colour, you would have to book them in for half an hour... then a gap of half an hour, and then another half an hour for the cut. (Linda)*

As part of her job, Linda had to perform a calculation to predict the length of time a booking would take depending upon the service required, and then find a suitable slot in the salon diary. She described making a number of mistakes that led to insufficient time being allocated and subsequent double bookings. Even though taking bookings was a small part of her role, the errors she made in that area had consequences for the business and caused her embarrassment.

Some of the participants in the *CDD* group attempted to perform time calculations using visual manipulation skills. For example by adding time they imagined how the clock hands would move over a particular period seeing quarters and halves of hours as angles of 90 and 180 degrees respectively. They may not have been able to describe the mathematics of the angles if asked, but they could recognise the shapes that were made. This idea of being able to judge angles through experiences rather than mathematical knowledge was described by Linda when she was cutting hair as a hairdresser:

*If someone wants layers, depending on the length of the layers or how short they want the layers, there are different angles. (Linda)*

When I questioned Linda further about angles it was clear she was unable to describe angles from a mathematical perspective in terms of estimating degrees, but she was able to recognise the different shapes that angles make:

*[My supervisors] always demonstrated and showed it in pictures, so I could just sort of copy, which I found easy. And then as time went on, it just became second nature and I would know where my hands were supposed to go. (Linda)*

Participants who preferred visual learning such as those in the *CDD* group were able to make approximate time calculations by imagining the hands moving. Alison considered increments of time as sectors on a circle:

*It’s not really the numbers that I care about I just, I can see a clock in my brain and I just know, it’s like these pieces of cake I’ve got allotted time for. (Alison)*
This skill was not evident in students aligned with the DYO category, who preferred to calculate time numerically using an arithmetic strategy. Heather was one of the more academically successful DYO students, but still struggled to perform time calculations when time was counting down. This suggests she was using a procedural strategy that she had been unable to adapt to time counting down rather than forwards. Had she had a better understanding of time as a system of measurement then she may have been able to recognise a system counting down as an indicator of proximity to an event. As switching from time counting up to counting down caused her such difficulty, it seemed that her grasp of time calculations may be procedural rather than conceptual.

9.4.4 Punctuality

Participants struggled with punctuality due to a combination of the time-related issues discussed in this section. Cappelletti et al. (2011) observed that dyscalculic individuals “frequently report poor ability to appreciate time which is often exemplified by their unreliable punctuality at appointments or by their inability to plan activities” (p364). Dyslexic and dyspraxic individuals are also known to struggle with time management (see sections 4.3.1 and 4.3.2)

Within this thesis, time is mostly considered as a social construct, with fluency in astronomical time and the ability to synchronise activities with others an important part of academic and social life. Membership of most societies is dependent on observation of certain social and cultural practices including meeting other people and taking part in group activities. An individual's ability to be punctual can have significant implications for their place in society. Lateness, whilst deemed impolite in casual social encounters, can become a disciplinary issue and even cause for dismissal from employment, as observed in my own study where Linda recounted as a teenager being sacked due to her continual lateness in returning from lunch breaks. Being late for appointments was the participants’ main time-related concern leading to a number of individualised coping strategies, as shown in the next section.

9.4.5 Perception of the passage of time

The majority of participants reported difficulties in assessing the amount of time that had passed, or 'sense of time', as illustrated by Olivia.

*I really didn't know how long 15 minutes was I still don't. I don't know how long we've been sat here without looking at my watch.* (Olivia)
Seven of the participants, including everyone within the severely dyscalculic (SDY) group and Quentin, described significant difficulties with a sense of the passing of time. Six of these participants reported a need to constantly check the time, typified by Fiona.

*If I have to be somewhere, I constantly check [the time], just to try and reinforce it, to try and get it sinking into the memory banks, but without a lot of success.* (Fiona)

Cappelletti et al. (2011) undertook the first study to explore the relationship between dyscalculia and sense of time. Their study only explored dyscalculic individuals’ ability to estimate time, for example how long it takes to make a cup of tea, and not the ability to judge the passage of time. As discussed in 9.4.2, if the parts of the brain used to conceptualise numbers are also responsible, at least in part, for the perception of time, then these difficulties could also be a characteristic of dyscalculia. Pellerone (2013) suggested that if the part of the brain that causes dyscalculic individuals to create a malformed logarithmic mental number line (see section 3.8.2) is also used for temporal estimation, then this could be responsible for the tendency for dyscalculic individuals to underestimate time. However, in my study, sense of time was not always characterised by underestimation, as shown by Quentin:

*And I sat, I was doing something, and then I began to panic, because I thought much more time had actually passed than it actually had. As it turned out, only a couple of minutes had passed, so I had plenty time to make the train, but I had thought I had been sitting doing what I was doing for a bit longer.* (Quentin)

Although neurotypical individuals may experience situations like this occasionally, for the participants in my study they were such regular occurrences that the persistence and frequency of the difficulties strongly affected their sense of identity (Chinn & Ashcroft, 2006). Variation in the perception of time seen in this study does not necessarily discount Pellerone’s theory, as dyscalculic individuals’ mental number lines could be imperfect in unpredictable ways, and not always logarithmic (Dehaene, 1999). In my own study, this was demonstrated by Linda’s account of missing out large sections of numbers when counting, which is described in section 9.3.1.

Difficulty in judging the passage of time could affect a dyscalculic individual’s functioning within society and participation in social activities. For example, judging the appropriate duration of a break at work, as shown by Linda, or an acceptable waiting time in a restaurant, requires an understanding of societal norms as well as a sense of the passage of time.

The ability to arrive on time for an appointment was also a strong theme to emerge. All of the participants showed great awareness of their punctuality issues and sought to pre-
empt and address their difficulties in this area. Participants universally spoke about overcompensating on travel contingency by leaving excessively early for appointments, resulting in early arrival times. Interestingly, Alison considered that she no longer had a problem with timekeeping because her strategy of arriving extra early was an integral part of her routine, a strategy already recognised to be favoured by dyslexic HE students (Hunter-Carsch & Herrington, 2005):

_I’ve always been good with time, because I’m never late for anything... I’m always ten minutes in advance, even earlier. I don’t mind sitting round, I just can’t be late._

_Alison_

Initially Alison’s remark appeared to show she did not have any time related difficulties, on further questioning however, it became clear that she did have a difficulty with time, but her coping strategy had become so effective she no longer considered that she had an issue. Other participants took further steps to organise their lives in order to reduce the detrimental effects of their time issues. Olivia and Linda had both developed exceptional organisation skills to create a system of smart phone alarms to guide them through the day:

_My morning schedule is a series of alarms, so I’ve got an alarm that wakes me up, I’ve got an alarm that tells me that it’s time to take the dogs out, I’ve got an alarm that tells me it’s time to leave the house to go and catch the bus, I’ve got an alarm that tells me to have breakfast._ (Olivia)

Although this coping strategy appears highly prescriptive, it allowed users of it to maintain a routine despite their time management difficulties. This particular strategy was only possible due to their strengths in terms of organisation and attention to detail, and would not be suitable for all dyscalculic individuals.

Quentin used an alternative strategy of creating a lifestyle that avoided dependency on time calculation wherever possible. For example, he chose to live next to the train station in order to avoid having to calculate travel times between his home and the station to catch the train for work. Quentin also recognised that his time management problems exacerbated his anxiety issues and he chose deliberately to keep his workload manageable by scheduling free time into his day. Most of these strategies relied on routine, which he felt created an inflexible lifestyle and hindered his ability to interact socially.

Linda employed a strategy of defining her own units of time in terms of duration of everyday tasks:
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I generally judge it by a cigarette, because I smoke... It’s usually between seven and ten minutes to have a cigarette, depending on if I’m talking at the same time. So, I tend to judge distances when I’m outside by a cigarette. (Linda)

This new time unit avoided the need to deal with the abstraction of astronomical time and created a version of time with a real-life meaning that Linda could experience, which could be seen as similar to the construct of socially relevant units of time such as the roasting corn example described in section 3.6. This strategy could be adapted on an individualised basis, utilising any task or experience with a measured, fixed duration. Possible examples include songs on an MP3 player or the time taken for the kettle to boil.

The diversity of innovative and meticulous coping strategies observed in the study illustrates the importance of time to the participants, for their own self-esteem and for their ability to cope with everyday life. Whilst ‘being bad at maths’ did not cause particular distress for some individuals, all the participants expressed serious concerns about their issues with time. Quentin illustrates the impact of time management issues on his self image, when despite living next to the train station, he still struggled with judging time:

The amount of times I’ve missed the train is actually a little bit embarrassing.
(Quentin)

Whilst issues around time management were reported as a source of frustration and a challenge, discussion around the students’ coping mechanisms was very positive. All the participants with the exception of those the highly anxious group (HAnx) described their approach to problem-solving and development of individual coping strategies with pride. Bradley felt that it was a positive trait that he always arrived early for appointments, and saw it as a worthy attribute respected by society. Olivia’s devotion to her finely detailed schedules and alarms was explained enthusiastically during the interview with no evidence of embarrassment. This source of pride has positive implications for the self-esteem of dyscalculic students and could be incorporated into strategies for supporting their learning.

9.5 Application of mathematics

This section examines the application of mathematics and the themes which were most prevalent in the participants’ interviews in addition to time. The mathematical topics that caused most concern to the students were standardised units, statistics, money and the mathematics issues around fitness to practise.
9.5.1 Standardised units

The participants described having little sense of understanding quantities when given measures in standardised units. Where the participants were asked whether they could estimate an everyday standardised amount, they all showed little confidence in their abilities. The most common examples given were distances and weights:

*If someone was trying to get kilometres, which I just don’t understand, across to me… I still wouldn’t quite grasp that there was a specific distance and what that was necessarily… I don’t conceptualise things like that. I’ve got a slightly better idea of metric… [Although] I always know six foot, roughly, as that’s the height of my husband.* (Nancy)

Julie, even as a high achiever [HAch], also struggled with using standardised units as she claimed she couldn’t visualise a centimetre. The reason for the difficulty in understanding the meaning of standardised units was explained by Olivia:

*If you told me something was 35 tonnes, I don’t know what that means. If you tell me it’s the size of a house and weighs four elephants or whatever that makes sense to me.* (Olivia)

Olivia’s example is perhaps flawed as many neurotypical individuals might struggle with the concept of tonnes, but both Nancy and Olivia’s statements emphasise that standardised units have no context. Olivia had a sense of the number 35 and where it would fit on the number line, but the addition of the word tonnes made the value meaningless to her. Percentages were also mentioned as being problematic:

*Five percent of the population, that five percent, it doesn’t mean anything to me. If you say fifty percent, right, half the population, but five percent doesn’t mean anything to me.* (Deborah)

Where quantities have been embedded into a system of standardised units, dyscalculic individuals are likely to experience difficulties for a combination of reasons. Firstly, numerosity issues make relevant comparison of measured values difficult. Secondly because the dyscalculic learner struggles with non-cardinality, the added standardised unit can transform the number into something different with little or no meaning. They can recognise that the number refers to a counting of objects, but cannot associate the standardised unit as a tangible physical concept. This leads to issues with iconicity (see section 9.5.2.1) where the abbreviations used to represent standardised units bear no resemblance to a physical dimension. This is another form of abstractness that negatively impacted the participants need to experience life tangibly within context.
One exception to the confusion around standardised units was the pound sign. None of the participants described difficulty with the pound sign, and two of the *co-occurrence of dyscalculia and dyslexia (CDD)* participants felt that thinking of calculations contextualised in monetary terms made mathematics easier (see section 9.5.3.1).

### 9.5.2 Statistics

Every student in the sample struggled with statistics at some point within their educational journey, and all but one of the students (Bradley studying a Textiles degree) had encountered statistics at tertiary level, which is the focus of this thesis.

All the participants in the study felt comfortable with bar charts, and to a lesser extent, pie charts (see section 9.5.2.4), but described some difficulty with more complex graphs such as scatter plots. When decoding a graphical representation, a student is required to interpret multiple sources of information which may include text, legends, axes and labels (Henderson, 2012). Three possible explanations were identified as to why the participants in my study reported the more advanced forms of graphical representation to be more difficult to understand. The first of these is iconicity, which describes the readability of a pictorial image conveying information, and is discussed further in section 9.5.2.1. The other explanations are multi-dimensionality and axis scales, which refer to the ability to interpret an x-y graph. Both iconicity and multi-dimensionality are connected to conceptual understanding of graphs and how the viewer interprets meaning, whilst axis scales are intrinsically mathematical and linked directly to the ability to read number lines. With iconicity, all participants struggled to relate more complex representations to real-life scenarios, and needed more pictorial representations to help bridge the gap. This difficulty was least evident in participants in the *CDD* group, who appeared to have greater visual skills and were better able to cope with abstract representations.

#### 9.5.2.1 Iconicity

All the participants in the sample struggled with the abstract qualities of graphical representations which I refer to as ‘iconicity’. The term iconicity describes how a pictorial representation of real-life could be considered as either abstract or concrete. For example a traffic warning sign with a picture of a deer may be considered as iconic, as the meaning of ‘beware of deer in road’ is easy to interpret, whereas a national speed limit sign (a white circle with black diagonal stripe) could be considered as more abstract as the information it is attempting to convey is less obvious. Iconicity is the conceived similarity by an observer between a representation and its meaning, or how abstract a
concept is from the object it is meant to represent (Morris, 1955; Moles, 1968). Although its origins are from outside the fields of neurodiversity and mathematics, the term iconicity can usefully be used to describe graphical representations in mathematics. A pictogram, for example, that contains images of an object can be said to have high iconicity because it can realistically depict what is being represented. Graphical representations often try to demonstrate complex numerical ideas visually, e.g. proportion (pie charts), variable relationships (scatter graphs), rate of change (distance-time graphs) or value classes (histograms). As graphs become less iconic and more abstract, their meanings become more difficult to interpret and relate to their inherent subject matter. Fiona was the participant who appeared to struggle the most with iconicity because it was important to her course. Iconicity issues therefore could be course dependent:

*I can understand it in a table, so this is where I get to the point of going "I get that, why do I want to draw a graph?"* (Fiona)

Fiona understood that graphical representations were being used to convey quantitative information, but she was unable to comprehend how this information was being incorporated into the graph, how it should be interpreted, and how it was useful. This is because the graphical representations had become too abstract and no longer contained any real-life meaning. She added:

*I was there and I collected this data, so I was on the ground doing it. That’s fine, I can measure you out a quadrot of 100 metres squared and I can count the trees in it and I can measure the trees. You ask me to interpret the data and that’s a different, that’s a whole different task.* (Fiona)

This detachment from tangible real-life scenarios led Fiona to question why data that had previously been understood was now being represented in a format that appeared to have no meaning. Other students expressed similar feelings, with this statement from Julie being typical:

*I kept saying, well, “Why are we doing this? Because I can’t see the logic in it.”* (Julie)

When the data was not familiar to the participant, the problems were exacerbated, and then the abstract nature of the graphical representation formed a barrier to learning. This may not be as applicable to participants in the co-occurrence of dyscalculia and dyslexia (CDD) group, who generally preferred graphical representations to text. Comparison of learning styles and discussion of how neurodiverse students engage with differing information formats can be found in section 10.2.3.
Many researchers have explored processes of graph comprehension in neurotypical learners (Cleveland & McGill, 1985; Simkin & Hastie, 1987; Lohse, 1993), but “relatively less research has examined the factors that can moderate the extent to which different viewers engage in such processes” (Okan & Garcia-Retamero, 2012, p199). As there is little understanding of the processes underpinning graphical literacy within the general population, discussion around neurotypical individuals’ experience of graphical representation may not be applicable to the neurodiverse population.

### 9.5.2.2 Multi-dimensionality

All the participants in the dyscalculia with numerosity issues (DWN) category described difficulties when graphical representations had two axes of continuous data, such as scatter plots. Nancy’s explanation was typical:

> It feels like that when you’re trying to plot graphs. I kind of get the principle, but it’s trying to count numbers up and get the right across and I’d always get it wrong and then it would be just a mess. (Nancy)

Nancy struggled to locate points on the graph; she could cope with one axis dimension, but plotting in two directions concurrently caused confusion. She was able to comprehend that one variable was increasing, or ‘counting up’, but struggled to relate that to a second simultaneous activity with another variable. Although some of the participants, like Maggie, felt able to read points procedurally within a Cartesian system, they were unsure of why there were two associated numbers:

> I would have to use a ruler to be able to match up the space with the number, or a piece of paper with straight lines...I would be able to find the number, but I’d struggle to understand what it meant. (Maggie)

Maggie could find a simple integer coordinate on a two dimensional graph by employing a learned process of using a ruler to find the cross section of two number lines, but this intersection point was an abstract construct that had no meaning. For Maggie, an object should have a single number that determines its cardinality, or possibly a representation of order.

These difficulties, however, have been shown not to be insurmountable. Trott (2010b; 2011a) described a dyscalculic student, Liam, who similarly found a time-distance graph to be problematic:

> The horizontal axis... was equivalent to the number lines he had been considering. He appreciated that time was ongoing. The problem now was that he was unable to see that simultaneously the distance was also changing (2011, p58).
Trott went on to describe the serendipitous resolution:

[Liam] was unable to see that the distance was also changing (in this case increasing) simultaneously. The graphs were re-drawn many times without the understanding being present. It was only by chance, that on one occasion he drew the graph with the vertical axis on the right hand side, and he had a 'eureka moment'. He said: "it’s climbing up the wall!" (2010b, p74)

Trott observed that this was a pivotal moment for Liam and is an example of how individualised support can help dyscalculic students find their own ways to overcome conceptual hurdles and make substantial progress (see section 10.4.1).

### 9.5.2.3 Axis scales

As well as the abstract nature of graphs, demarcation of the axes was another area where many of the participants encountered difficulty with graphical representations. In section 9.2.4.3 I discuss how participants in the study struggled with decimals generally, and it is therefore predictable that this difficulty may translate into the reading of graphical scales where rational numbers are involved. Although Bradley did not use graphs on his current course, he was typical in describing an issue that was raised by several participants:

This is really stupid, but like on the scales if there was, if it was like 0.00 something, then I would panic. But if it was just like one, two, three, four that was fine. If it was like 0.00065 ... 'point somethings’ used to make me panic. (Bradley)

Unlike the most severely dyscalculic (SDY) group participants, Bradley did not appear to have problems comprehending the existence of non-integers (see section 9.3.4). He struggled, however, to translate written decimal nomenclature into number meaning, which may have been compounded by his visual stress and its impact on his ability to read a large number of consecutive zeros.

The participants’ difficulties with decimal numbers had a clear impact on their ability to read and interpret graphs that contained decimal data. In addition, for students in the DWN group, the issue of reading axis values was not limited to decimals. Maggie’s dyscalculia characteristics were particularly profound but her experience of graphical axes demonstrates the fundamental misconceptions that can occur. Maggie considered only consecutive integers to be valid and found that any format of number line that did not conform to consecutive integers was incomprehensible (see section 9.3.4):
I would like it all to be labelled [referring to numbers], but they don't label it all. But that's when I get confused. But if it's like that one, it's better [pointing to a graph where all numbers are shown]. (Maggie)

Difficulty with interval labels is most applicable to decimals as they have been shown to be a potentially confusing number representation, but the issue may also apply to the labelling of integers. Two ways of marking integers on an axis were identified as particularly difficult to interpret. Firstly, missing labels, where the reader is expected to determine the value of an unlabelled interval mark by its relative position to other labelled indicators (see figure 21). This was a difficult skill for all participants in the DWN group, and any subdivisions that were not labelled had little meaning.

![Figure 21 - Axis with missing labels](image)

The DWN group participants reported confusion as the number goes from five to ten, and did not understand that the unlabelled intervals refer to the missing integers. The second issue is one of intervals greater than one with no intermediate demarcation (see figure 22). The reader would be expected to recognise that the intervening integers have not been shown for reasons of readability or space. In both cases Maggie would describe the axes as not having “proper counting” as she is expecting to see a six follow the five.

![Figure 22 - Axis with missing tick marks](image)

The learners with most severe dyscalculia in the DWN group did not recognise these alternative number sequences as valid. When asked about reading from a scale that went up in tens, Maggie commented:

*You can’t do it from counting. I find those really hard, but I’ve got to learn them.*

(Maggie)

Sequences that did not conform to “proper counting” were not within her number conceptualisation domain and were treated as a meaningless number-fact that had to be procedurally learnt. Thus intermittent axis intervals could render the whole graph
incomprehensible. With an alternative axis design that took account of these issues, the participants may have been able to access the graph, although this may result in a graph that may be too cluttered or too large. Displaying all the natural numbers on a scale, rather than intermittent values could remove one barrier to learning for dyscalculic students.

9.5.2.4 Simple graphical representations

Graphical representations which are specifically designed to show comparative data were the easiest for all the participants to understand. Deborah was typical of the participants in the study in that she was aware that more advanced forms of graphical displays may be beyond her comprehension:

*A bar chart is easier for me to interpret. I can interpret that but anything more complex than that... Anything more complicated and I’m finished.* (Deborah)

For all the participants, the bar chart seemed to represent a baseline of graphical literacy; it was the only representation with which all participants in the study felt a degree of comfort:

*Like, with a bar chart, I would say, “That one is higher than that one, so that one is more and that one is less,” rather than looking at the specific numbers.* (Linda)

Linda, one of the participants in the *DWN* group, felt confident in extracting information from bar charts. Although she had significant difficulties with numerosity and reading scales, she was able to see that one bar was larger than another and therefore represented a greater comparative quantity. Galesic and Garcia-Retamero (2011) showed that for most neurotypical individuals graphical representations were better than numbers for representing ordinal information, i.e. conveying the information that one quantity is bigger than another without specifying exactly how much bigger. However they did recognise that a significant proportion of their sample did not find the use of graphical representations easier to understand. The dyscalculia screening tool DysCalculiUM (Tribal, 2010) recognises that mathematical difficulty can be heterogenic and includes questions that test the student’s ability to understand visual representations, as well as questions that test skills more associated with dyscalculia such as numerosity, subitising and arithmetic (Trott, 2010c). In my study, all the participants were able to use the terms ‘taller’, ‘bigger’, ‘more’ and ‘less’, comfortably and accurately, which shows that their numerosity difficulties due to dyscalculia did not affect a direct visual comparison.
I like graphs. I find them easier to figure out. I’ve never really looked at graphs in order of a specific number, more of, “That one is more than that one, or less than the other one.” (Linda)

When considered in terms of iconicity, multi-dimensionality and axis scales, bar charts are accessible for dyscalculic learners. A bar chart can be viewed as a set of one dimensional bars, rather than any two dimensional configuration. With regard to the axis scales difficulty, when Maggie was asked if she understood how to read a bar chart she replied:

_I wouldn’t be able to say something unless it was proper counting or on the line. I wouldn’t be able to read it._ (Maggie)

As discussed in 9.5.2.3, reading a value from a bar chart may still prove difficult, but as the participants considered the comparison on bar heights to be the primary function of bar charts they still felt more comfortable with bar charts than other forms of graphical representation. Iconicity was also not an issue as the use of bars to represent an amount has become commonplace in society and relatively easy to interpret (Tversky, 2001).

### 9.5.2.5 Statistical data and inferential tests

Many participants reported struggling with statistical concepts during their HE studies. Averages, standard deviations and correlations had no meaning to many of the participants as they could not be related back to a real-life measure or number of objects, as described by Julie when considering a scatter plot:

_I’m not sure I understood the concept, so it’s difficult to explain it. But you get a graph and you have to work out from that whether there’s a positive response or a negative. I didn’t really understand it._ (Julie)

Julie was referring to the correlation on a scatter graph from her statistics module. She had been told that the direction of the line of best fit could deduce the correlation, either positive or negative. Although she was able to recognise the direction of a line and apply the correct term, the meaning of the mathematical concept and the significance of the gradient were beyond her current understanding.

Four of the _moderately dyscalculic (MDY)_ participants described having to use inferential statistical tests within their HE course. Perhaps surprisingly, these students had all managed to successfully utilise inferential methods to an appropriate standard to pass their module assessments. This appeared to be because in statistical packages such as SPSS and Excel statistical tests are ‘black box’ tools (Williams & Wake, 2006) where the mathematical understanding is not required for the user to interpret the result. As a
result statistical test modules are taught in a procedural manner using sequential steps of mouse clicks and screen shots (Gupta, 1999). This teaching format matched the preferred learning style of all participants in my study (see section 10.2.1) where conceptual understanding of the process was not being tested, only the ability to produce a result. Ellen referred to this as "parrot-style learning". The participants therefore had no need to search independently for an alternative method of learning. In addition, statistical software packages had eliminated the need to perform any mathematical computation. As there was little conceptual understanding of the underlying statistical processes, the participants in the MDY group, through hard work, were able to match or even outperform their neurotypical peers. Statistical tests were the only theme within the data where some participants felt they were equal to their neurotypical colleagues in the area of mathematics. These four participants each described a positive experience where they were able to participate in the activity with their peers and did not feel excluded from the social learning experience. For Alison this was particularly evident, as her additional hard work had resulted in an advantage over her peers, and they would seek her help:

*Whereas people in my hall, the clever people that were on my course... they’d just be like “Can we just look, make sure we've got the same answers as you...”* (Alison)

The experience of being part of a social learning group for mathematics not only enhanced Alison’s opportunities for learning, but gave her confidence in her own abilities that was unique amongst her mathematical learning experiences.

Quentin described one element of statistical analysis that was problematic, which was the interpretation of levels of significance or ‘p’ values:

*Some of the lecturers are very meticulous about putting the decimals in the right place when you’re writing up the significance of something. So, some of them prefer 0.005 and others prefer 0.05. I still don't know what the difference is.* (Quentin)

Quentin was aware that that the two ‘p’ values are different numbers, but was unable to appreciate why different results would require the use of a different number as he had no concept that the decimal referred to a level of confidence in a statistical finding. Comparing ‘p’ values against the statistical threshold would be difficult for all participants in my study as they all struggled with decimal representation as discussed above.

### 9.5.3 Money

This section explores the effects of dyscalculia on HE students’ relationships with money. Whilst previous anecdotal evidence acknowledged that dyscalculic individuals may
struggle to manage their own finances, including budgeting and the use of cash (Trott, 2011a), a literature search did not identify any research exploring the nature of those difficulties. The need to be fluent with currency is central to many socio-cultural experiences, so difficulties in handling money could lead to exclusion from a number of social activities. I have divided the theme of money into two subsections. The first explores physical money, or cash, and how the participants perceived notes and coins. The second subsection discusses virtual money, for example budgeting or economics calculations in an HE module.

9.5.3.1 Physical money

Six respondents described a preference, when forced to pay with cash, for using high denomination notes to avoid the mathematics involved in counting money. This avoidance strategy has been described in previous dyscalculia research (Peard, 2010; Trott, 2010b). Maggie was so averse to the idea of using coins that she would become annoyed if the cashier failed to give her a note amongst her change. Maggie was aware that sometimes she had received notes in her change, but was unsure under what circumstances this would happen as she was unable to build a relationship in her head between cost and tender amount:

*It's really annoying, because sometimes if you give them a note, they don't give you a note back... So, if you don't get a note back, that's really annoying, because you don't have one for next time.* (Maggie)

A mathematical understanding of the process of receiving change involves conceptual understanding of the subtraction operation. Due to Maggie’s lack of number sense she struggled to understand that when receiving change as part of monetary transaction, a subtraction was taking place. ‘Counting on’ is a strategy that is often employed by individuals who struggle with subtraction (Fuson, 1986), however Maggie did not appear to have developed this particular coping strategy, as she claimed to only be able to perform “minusing” if she had a number line or a calculator. As a result she had no sense of how much change she would receive, especially as multiple coins would feel like more money as she had non-cardinality issues with assigning values to individual coins. Through experience, Maggie had recognised that notes tended to be large enough to pay for objects, and therefore was keen to have notes on her person rather than coins. She was unable however to deduce that change of less than five pounds could not possibly include a note. Although when asked specific questions, Maggie was able to recall the values of notes in sterling, she preferred to refer to them by their colours, which again suggests non-cardinality issues and a need to view money through an easily observable property. The trait of referring to monetary notes by their colour has been described
before in a case study of a dyscalculic student (Trott, 2010b) and highlights that dyscalculic individuals can struggle to associate physical cash with a monetary value, as typified by Gemma:

[I] sort of panic when you’re staring at a purse full of change and going "I’ve got no idea what any of these coins mean". (Gemma)

Gemma’s difficulty in recognising coins could be another example of the non-cardinality issue. As she was viewing her coinage in cardinal terms, she had a sense of the number of coins she had, but was unable to assign an abstract monetary value to each individual coin. Gemma was a member of the high achievers (H Ach) group, which suggests that problems with non-cardinality may be a feature of dyscalculia generally, rather than restricted to members of the severely dyscalculic (SDY) category.

One scenario which was mentioned by two participants as being particularly difficult was when to offer extra tender to simplify the change. This is a relatively advanced mathematical concept of adding additional small coinage to the tender to ensure the difference becomes a whole number, and requires a strong knowledge of number bonds. Gemma, as a member of the H Ach category, was one of the participants who described this situation and struggled to understand the rationale behind the action:

[Overpaying] really confuses me. I really struggle to pay in that kind of way, as well, to make the change neat, because I just can’t figure out how that’s meant to work. It’s just something I don’t understand, and no matter how much I think about it, I can’t understand it. (Gemma)

This highlighted that members of the H Ach group do not necessarily have a significantly better grasp of number facts or arithmetic skills. Irrespective of individual strengths in other areas, the need to deal with money sometimes affected participants’ ability to take part in certain social practices. For example Nancy required a part-time job to support herself while studying for her first degree, and worked for a while at a cafe:

The first job I ever did was in a bar... [It] was horrific! I’d been there probably about three weeks and I’d been having to use the till and was finding that really challenging and it was a really old till as well, so you had to have a bit of paper and you were supposed to work stuff out yourself, and I was just getting it so consistently wrong. I kind of kept saying to them, “Look, please don’t get me on the till because it’s horrible and it’s not good for the customers either”. (Nancy)

Nancy eventually resigned from this job due to her embarrassment about her monetary difficulties. Her confidence in her ability to handle money was so low she accepted that she must be the reason for any shortfall during cash reconciliation.
Two participants in the *co-occurrence of dyscalculia and dyslexia (CDD)* group reported a lesser degree of difficulty with monetary transactions when using cash. This could be because the physical nature of money allowed them to experience it in a real-world context and mentally create relationships between the objects using kinaesthetic and visual skills (4.3.1). Glenberg et al. (2004) described this effect with neurotypical learners when they claimed that real-world contexts allow learners to mentally simulate and reify concepts that otherwise might be too abstract to understand. He uses the example where children manipulate toy animals to mimic the actions described by certain words.

In my study, I observed that the use of credit and debit cards has changed the shopping experience for dyscalculic individuals in ways which may not have been possible in the past. All the participants reported a preference to avoid paying with cash, which they found to be a stressful activity. Linda was typical in her preference to use a card wherever possible:

> I try to pay with cash as little as possible. I tend to pay with my debit card as much as I can, because then I don't have to deal with the numbers. (Linda)

When Linda talked of ‘dealing with the numbers’ she was not necessarily referring to a mathematical operation. Many participants described an anxiety response to the presence of numbers, whether or not there was any calculation involved. The use of debit cards appeared to reduce much of the stress faced by dyscalculic individuals, where the respondent was able to remember their personal identification number (PIN), something which was described as a challenge by participants in several groups.

> I've had the same pin number since God knows when. I always make sure I've got the same one because otherwise I can't remember it. (Julie)

It may have been expected that the participants in the *CDD* group would struggle to remember a PIN due to poor working memory (see section 4.3.1), but this was also reported as a problem for several of the *dyscalculia only (DYO)* group participants. This could be due to mathematical anxiety inhibiting working memory, making recollection of a PIN difficult as discussed in section 4.4.2.

### 9.5.3.2 Virtual money

All the participants described difficulties with performing calculations with money, either academically or within their own financial budgeting. Four of the participants described dealing with monetary concepts as part of their studies and they each recalled significant
difficulties performing financial calculations, including Julie who was a high achiever (H Ach) studying Law:

*The huge problem was if you were ending up having to work out damages and things like that and work out the tax or the Legal Aid contribution.* (Julie)

The theme of dyscalculic individuals struggling to participate in monetary social practices is consistent with previous literature (Chinn, 2009a). Financial management requires mathematical skills such as competence with the four operations, the ability to round monetary values to simplify calculations, and the ability to estimate these calculations when approximate values are required quickly. These tasks may be difficult for neurotypical individuals, so it is unsurprising that they were particularly problematic for the dyscalculic students in my study. The participants in the severely dyscalculic (SDY) group reported the most problems, which is consistent with their significant difficulties with the mathematical processes listed above.

Participants in the dyscalculia with numerosity issues (DWN) category highlighted a particular difficulty with recognising how much they were spending. For example, Maggie had little concept of how much money she needed in her account and therefore how to budget. At the time of the interview she was in significant debt:

*I know that I don’t have any money in it [bank account] at the moment, because yesterday my card got declined. But yeah, I don’t like to look at it [statement], because it scares me.* (Maggie)

Nancy struggled in the same way as Maggie, but had developed a coping strategy by only using physical cash, and not a debit card. By having a finite amount of money in her possession, she was able to restrict her spending, which she was unable to do using numeracy:

*My husband’s biggest bugbear is that I will just buy it. I’ll go, “I like that. I’m going to buy that” and he’ll say “How much was it?” and I’ll go “I don’t know”. It’s just, the money’s in my wallet and it looks like it’s going to cover it, fine... That’s why I have to be so, so strict with what I take out every week, or else it would all just go.* (Nancy)

Overspending could be explained by difficulties with place value (see section 9.2.3), numerosity (see section 9.3.2) or arithmetic weakness (see section 9.2), either singularly or in combination. Problems with interpreting place value can lead to errors in reading price tags and recognising the monetary value of an item. Numerosity issues can compound this problem by impeding the ability to recognise an acceptable price and what represents good value. Another possibility is that the dyscalculic individuals’
propensity for cardinal numbers can make monetary values seem abstract and feel counter-intuitive to a need to see numbers in terms of ‘counting’, and this idea is discussed in section 9.3.1. Poor arithmetic affected the participants’ confidence in dealing with money and performing financial calculations. Neurotypical individuals use number bonds to quickly recognise aggregate monetary values, whilst dyscalculia compromises this ability, necessitating a reliance on weak mental arithmetic skills. Mental arithmetic difficulties are likely to be related to mathematical anxiety, which is discussed in section 8.4.

The moderately dyscalculic participants described some coping strategies which helped with financial management, for example Quentin chose a strategy of deliberately under-spending to avoid financial difficulty:

*The account that I use for my bills, and just kind of keep it topped up as much as possible, which means that it's quite hard to save money. But it means that I don't incur any charges or miss direct debits and things. I just over-egg it.* (Quentin)

As Quentin struggled to judge how much money was required to cover expenditure such as direct debits due to poor estimation skills, he chose to be overcautious with spending to ensure he had enough money to cover his expenses. Quentin's need for a coping strategy to limit spending was likely to be a result of his anxiety issues because the highly anxious (HAnx) participants appeared more concerned than the other participants about the consequences of overspending. Quentin described feeling stressed at the thought of being overdrawn, which led to extra monetary precautions that were not reported by participants in the other groups. Although this strategy worked well in terms of limiting the likelihood of financial problems, it led to his exclusion from social activities as he would turn down opportunities due to the fear of spending too much money.

Participants in the CDD category tended to be better at trying to find practical coping strategies to help with their budgeting, as typified by Alison who was able to use a spreadsheet to help her with her finances, although she needed support from her father to develop it:

*I know how much I’m spending and I have an excel sheet so, like me and my dad did it and I know how much I can spend each week with my student loan, and so weekly I’d write in how much I’m spending... I can remember, I know how much I’ve spent this week and I know how much I spent last week, and I can probably remember the week before as well because it’s always in my mind.* (Alison)

Spreadsheets were likely to be helpful in several ways. Although dyslexic students may be expected to have poor working memory, they often have strong visual memory skills
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and a well-structured spreadsheet, with the use of colour, could have helped Alison to remember her current balance and have some sense of whether her spending was under control. The automation of mathematical operations is hugely beneficial as this is not only more efficient, but removes the arithmetic tasks that all the dyscalculic students find difficult. This could be particularly helpful to students in the CDD group as they were the most likely to make arithmetic errors due to dyslexia-related poor organisation of procedural strategies such as alignment of digits.

9.5.4 Mathematics required for fitness to practise

The fitness to practise (sometimes referred to as fitness for practice) of neurodiverse employees within the public sector has been the subject of much debate, as discussed in section 5.10. Fitness to practise relates to professional and technical competence, although specific definitions vary according to sector and professional body. For the participants of my study, fitness to practise became an issue when their dyscalculia impacted upon their ability to reach and maintain established professional standards. There were three students in the sample for whom fitness to practise was an issue: Deborah and Rebecca, who were both healthcare students, and Heather who was a trainee early years teacher.

The two participants studying for health care qualifications described difficulties with a number of specific tasks involving a variety of mathematical skills, for example taking a pulse or blood pressure, maintenance of fluid balance charts and the calculation of drug dosages. Rebecca described difficulty in weighing patients in clinic:

> What are the other little digits? What are the little pointers? Fair enough if it was bang on and you could identify it. If the number was there [points at an integer interval], right, I can see that. (Rebecca)

The task described is reading a value from a measuring device and transcribing it to a computer or paper form. From Rebecca’s description there does not appear to be a need to perform a calculation, such as converting units, or utilise a sense of numerosity to appreciate the value of the weight. As Rebecca was able to read the values when the pointer indicated an integer value, the issue was not with the scales as such, but with her understanding of decimals. This is similar to the participants’ issues with graphical axes discussed in section 9.5.2.3. She was unable to interpret the unlabelled marks between numbers and assign them a value. She was aware that when the pointer was not directly indicating a numerical value, she had to follow a procedure to provide a value that wasn’t shown, but due to her difficulties with either non-integers or place value she struggled to do this:
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99% of the time, I didn’t get it right. Fair enough if it was bang on and you could identify it. If the number was there, right, I can see that. But for some of them, you had to work out all that, and I was like, “I can’t figure that out.” (Rebecca)

Because of Rebecca’s lack of conceptual understanding she was unable to describe the process she was trying to perform, or a rationale for why she was doing it. In a similar situation in section 9.3.4, the severely dyscalculic (SDY) Maggie had adopted a rounding strategy of using the nearest whole number as she could not perceive non-integers.

Unlike Maggie, Rebecca seemed to have some awareness that there was a number that existed between the integer divisions, however she found it difficult to describe or formulate this number. This quote by Rebecca is also another example of using percentages as a scale of correctness as described in section 9.2.4.1. She may not understand what a percentage is, but she is aware that quoting a number close to one hundred indicates a greater frequency.

Both healthcare students in the study reported difficulties with different forms of non-integer representation, (see section 9.2.4) and in particular, conversion from one format to another. When Rebecca referred to difficulty in dealing with half tablets, I initially assumed the difficulty was in keeping track of the half tablets, or in physically splitting them, but on further questioning it became apparent that she was unable to associate the decimal representation of ‘0.5’ with a half tablet.

And when I went into nursing, say sometimes if you’re doing the tablets and you halve a tablet, it took me a while to think what 2.5 was. (Rebecca)

Rebecca was describing a lack of conceptual understanding with regard to non-integers, both in how they exist contextually in the real world and how they are represented symbolically (see section 9.2.4). She may have been able to use decimals in some way procedurally, possibly on a calculator, but she could not relate ‘0.5’ as being equivalent to a half, and what that would correspond to in a drug dose, and this missing connection could have led to drug miscalculations. The fact that Rebecca was able to describe the nature of this difficulty demonstrates that she has improved her understanding and was able to recognise that ‘0.5’ represented half a tablet, either through a greater conceptual understanding of non-integers or by symbolic matching of the decimal to a concrete object of the half tablet.

Deborah, as a participant in the high achievers (HAc) group, was better able than Rebecca to recognise where she had mathematical difficulties and develop coping strategies that minimised mathematical processing. For example, when taking a pulse
she would count the rate over a full minute rather than count for fifteen seconds and multiply by four, which was standard practice.

I still had to work it out each time. So I would just check the pulse for a full minute, rather than put myself under that pressure. (Deborah)

The high pressure environment of the clinical area added another dimension of difficulty for the two dyscalculic healthcare students. Application of time limits has already been shown to exacerbate the difficulties experienced by dyscalculic students (see section 8.4.3) and the need to complete tasks promptly added to the pressure on clinical placements. Deborah felt that she would be able to perform most tasks required in her role if she had more time, but the additional pressure made her produce poorly organised written notes which made her self-conscious:

In places like intensive care, when you’ve got lots of figures that are going on the chart, I’d noticed I was scribbling things out and having to re-write them and it wasn’t organised, like other people’s was so pristine, and mine was, I wanted it to be accurate but I was struggling to get it accurate. (Deborah)

Deborah felt that under pressure, her difficulty with reversing digits was more pronounced. This shows that it is not just drug calculations that could be an issue, but the transcription of numbers, which is already known to be an issue for dyslexic health practitioners (Shellenbarger, 1993). When she was able to concentrate, she did not feel it was an issue. Deborah recognised the importance of accuracy with numbers when completing medical notes and was aware of her difficulties and her need for safe practice. Section 12.3 explores how participants successfully used constant re-checking (hypervigilance) to tackle these difficulties, but this coping strategy requires additional time which Deborah felt was unavailable in certain busy environments such as Accident and Emergency (A&E).

Calculators have been described as an invaluable coping tool by dyscalculic students and are discussed more fully in section 10.3.3. For the healthcare students in this study, calculators were considered an essential tool, without which they would be unable to perform their role. As many neurotypical nurses carry calculators to aid in drug calculations, a dyscalculic nurse using a calculator would not seem out of place:

I notice now that a lot more nurses carry calculators, or they use their mobile phones which is one of the most common things. (Deborah)
Rebecca chose to use a large calculator which may have highlighted her difficulty, but she felt it minimised the chance of her making a mistake and may possibly be linked to visual stress:

*Everyone used to laugh at me, because I have a big calculator... Because see if you gave me a small calculator? I can't cope with that.* (Rebecca)

Rebecca felt unable to recognise when a data entry error has produced an incorrect answer. As a member of the *dyscalculia without numerosity issues (DWO)* group she had difficulty comprehending operations and how the operands combine to form a new number. Participants in the *dyscalculia with numerosity issues (DWN)* group could have greater difficulties recognising a sensible result as the ability to estimate is a component of numerosity skills (Butterworth, 2002). As the use of calculators is now commonplace on the ward, they need not be considered a reasonable adjustment.

Although not strictly a coping strategy, the use of standardised tools for documenting numerical patient data was cited as helpful by the healthcare participants. This had the dual benefit that the student could develop familiarity with the chart in order to become proficient in its use, and also that when moving between wards on clinical placements, the documentation encountered was the same. Rebecca, for example, explained that by employing a procedural strategy, she had learned to document and interpret data using the Scottish Early Warning System (SEWS) observation chart used locally, and felt confident in her ability to monitor patient condition:

*I can recognise on a SEWS chart, which basically is their observation chart, I can recognise a trend. I can recognise when someone has got a high temperature.*

(Rebecca)

The SEWS chart used by Rebecca can be found in appendix O and contains features that may cause difficulty for a severely dyscalculic practitioner, such as intervals in the scales rather than consecutive integers. Appendix O also shows a preferred format for body mass index (BMI) charts which she had practised with and was able to use effectively:

*When you weigh a patient and you take their height, you have to look at their... score, so you've got a chart that calculates their BMI. That's difficult.* (Rebecca)

This chart had been designed to help a practitioner read data and interpret graphical representations by having individual BMI scores in each cell, and the y-axis scale labelled to show as many intermediate values as possible to reduce the amount of user interpolation. Appendix O also includes a contrasting less user-friendly BMI chart that requires the practitioner to estimate values along a curve or axis.
Rebecca was aware that unfamiliar graphs caused her difficulty, and a sudden change in ward documentation could threaten her fitness to practise. Reasonable adjustments for dyscalculic practitioners must therefore incorporate sufficient time to adjust to any changes and obtain proficiency before using them in the clinical area.

For trainee teacher Heather, the mathematical requirements were different. Although there was no regimented mathematics curriculum in the early years setting, the teachers were expected to encourage the children to have an enthusiasm for mathematics, and facilitate their natural interest in numbers, measuring and shapes (Department of Education and Employment (DfEE), 2000). The Department for Education and Employment guidelines highlighted that children were expected to be able to count to ten and perform simple addition and subtraction using fingers by the end of their early years education. Heather described a role play activity called the ‘five spacemen’ which was designed to help children count down from five. Each pupil would take on the role of an astronaut, and use the countdown of a rocket as a context:

*We just did ‘the five spacemen’. They got to dress up as spacemen with numbers on, and put the numbers in order, and if I took one away then how many spacemen have I got? (Heather)*

The situation with Heather differed from that of the healthcare students, in that there were no complex mathematical tasks involved within her daily teaching role. However, qualification as a teacher required successful completion of the Qualified Teacher Status (QTS) test (see section 12.4) and this requires a level of mathematics understanding beyond that of the curriculum of early years’ children. At the time of interview Heather had to pass QTS tests before completing her course, whereas new starters now cannot begin the course without passing the QTS tests in advance. Williams (2008) suggested in a report investigating early years mathematics teaching, that a higher level of mathematical knowledge is required as "a teacher cannot explain to her students the principles underlying the multiplication algorithm if she does not explicitly understand them herself" (p8). Heather disagreed with this perspective as her lack of conceptual understanding meant that she could not appreciate how a greater mathematical knowledge is requisite to scaffold young learners into forming concrete mathematical ideas. This is an example of how a dyscalculic individual appears to view mathematics differently to a neurotypical person, as discussed in section 3.7. Heather viewed mathematics as a set of procedural techniques to solve real-world problems. These procedures are unconnected, and needed to be remembered as for her, they could not be deduced. She felt that mastering these techniques to the level of the children she would be teaching was sufficient to fulfil her role as a teacher. As Heather believed that
mathematics was intrinsically a set of procedures, she would only be able to teach them using a procedural method. She would therefore find it difficult to frame learning for children who needed a conceptual learning style to grasp mathematical understanding.

9.6 Summary and discussion

This chapter catalogued the mathematical difficulties described by the participants. I chose to place all mathematics discussion into a single chapter, as mathematics discussion was originally spread throughout the results chapters corresponding to context and it became increasingly difficult to connect mathematical ideas.

Arithmetic in general was problematic to the participants which is consistent with current definitions of dyscalculia. Difficulties with arithmetic were not only evident during academic study, but were equally prevalent in everyday life highlighting how much dyscalculia affected the participants’ ability to integrate in a social world. The participants showed a good understanding of the concepts of addition and subtraction, although the process of performing subtraction without a calculator was described as difficult by the severely dyscalculic participants. The concept of multiplication was understood by all except the most severely dyscalculic participants, although strategies for tackling multiplication tended to revolve around repeated addition. Division was problematic for most participants, who described both the concept and the process of division as difficult to comprehend. Number facts such as number bonds and multiplication tables were not well understood, probably for three possible reasons. Firstly, mathematical anxiety or a co-occurrence of dyslexia had reduced working memory and made it difficult for number facts to be retained in long term memory. Secondly the difficulty with mathematical concepts due to dyscalculia meant that the students failed to form cognitive links between number facts, preventing them from becoming secure and able to be committed to memory. Thirdly, lack of mathematical skills prevented the students from extrapolating existing number facts into new facts, such as realising that 60 plus 20 equals 80 based upon knowing that six plus two equals eight.

All participants reported some degree of difficulty with non-integer formats. The difficulties involved all representations, although the students in the CDD category had more success with fractions as they can easily be represented visually, which is a known strength of dyslexia. Students in the dyscalculia only (DYO) category however disliked fractions. Although many participants were comfortable using percentages, they perceived them more as a scale of correctness as used in assessment marking schemes rather than as a proportion of a whole. The most unexpected finding from the data
concerning non-integers was that two of the most severely dyscalculic students had difficulty comprehending a non-integer number, and one was unable to describe the purpose of intervals between integers on a ruler. The comprehension of using numbers to represent incomplete quantities should be explored further from a conceptual perspective. Understanding the existence of non-integers may be another fundamental difficulty of dyscalculia, similar to the characteristics of the Butterworth model.

By examining in detail the most fundamental characteristics of dyscalculia, it can be seen that only a handful of the participants in my study would be considered dyscalculic under the Butterworth model. These participants described problems with counting, subitising and numerosity that are consistent with the findings of researchers who have documented the most severe types of mathematical difficulty. The remaining students however did not describe the same level of difficulty, and have reported more arithmetic-based issues that would be consistent with an identification of dyscalculia using a discrepancy model such as DSM-5 (American Psychiatric Association (DSM-5), 2013).

Counting was a mathematical skill that was only problematic to students in the dyscalculia with numerosities issues (DWN) category. Members of this category could not reliably count above one hundred, and one participant had difficulty counting two digit numbers, with a tendency to insert numbers randomly. All the participants had difficulty with counting backwards or forwards in steps of two, suggesting that counting was a mostly memorised process rather than an inductive one.

Subitising difficulties have been shown by researchers such as Butterworth to be a strong indicator of severe dyscalculia. Before my study, I had only ever seen subitising in terms of an experimental test, with no real-life application. This research however provided examples of how subitising is useful in practical terms, especially with regard to recognising the number of digits in a number. The ability to subitise allows an individual to easily compare numbers with a small number of digits. Without this skill, the number of digits would have to be counted, slowing down the process. Subitising therefore has a crucial part to play in the determination of place value.

Non-cardinality is my own term to describe the use of numbers to assign values to items that are not related to their physical attributes, such as size or weight. The issue appeared prevalent throughout my study, and was a possible explanation for a number of difficulties described by the participants. In everyday life, pricing of goods is the most common example, as items have a commercial value that is independent of physical attributes, and can only be recognised through a price label (usually only displayed on the shelf) or socio-cultural awareness of the worth of the item. It is possible that non-cardinality issues are discussed in mathematics education literature under a different
name, but I am yet to find any reference. Dyscalculia research has generally focussed on numerosity issues, which is difficulty estimating cardinal numbers, but my data has shown that use of numbers in non-cardinal relationships was also a major problem for dyscalculic HE students. Dyscalculic individuals’ relationships with non-cardinal numbers would be an important area of further research in order to discover whether the focus on numerosity issues has excluded a vital aspect of dyscalculia.

The mathematics involved in managing money has been shown to be a cause of significant difficulty for dyscalculic students, with all participants discussing monetary matters at length. These issues involved both the handling of physical money and performance of financial calculations. The tender process at tills was an area of particular difficulty due to the issue of evaluating coins and notes, and the mental arithmetic required to aggregate money to a required amount for transactions. Non-cardinality significantly contributed to monetary difficulties as many dyscalculic students struggled to understand how the monetary value of a purchasable item, note or coin was not related to numerosity.

Heavy reliance on the use of a debit card as a tool had removed many of the issues involved with handling physical money for participants. Difficulties with recalling PIN numbers notwithstanding, all participants reported a preference to pay with a card, which may also be true for many neurotypical individuals. For the dyscalculic students, however, it was seen as a necessity to gain access to the experience of shopping, rather than just a useful tool. The debit card had become a mediating tool that allowed the dyscalculic students to share a common socio-cultural practice without fear of humiliation, and therefore reduced the risk of social exclusion. However, the use of debit cards had sometimes created other issues for the participants, with one participant reporting significant financial difficulty exacerbated by the use of card payment. One consequence of reliance of debit cards was that the participants were less able to manage their spending as they were not limited by the amount of cash on their person, leading to overspending.

Statistics was the most commonly raised mathematical topic with regard to HE. This is because many courses that are not physical sciences include a statistics module. Three areas of difficulty were identified in the field of statistics: iconicity, axis scales and multi-dimensionality. Iconicity in this context refers to the abstractness of a graph, and how easy it is to interpret its meaning. This difficulty was least evident with participants in the co-occurrence of dyscalculia and dyslexia (CDD) category, who appeared to have greater visual skills and were better able to cope with abstract representations.
The second theme pertained to axes and the demarcation of intervals, where problems with number lines had the effect of distracting the participant from data within the graph. Axis scale difficulties were predictable as dyscalculic learners are known to struggle with number lines. Gaps in numbering or unlabelled intervals were described as confusing, and made it difficult to read values. Participants struggled to interpret the meaning of numbers on the axes where intervals increased in formats other than continuous integer sequencing. Students in the DWN category particularly struggled with integer scales, whilst all participants reported problems with decimal intervals.

Multi-dimensionality refers to an x-y plot where a concept can be related to two variables changing simultaneously. A dyscalculic learner may be able to comprehend, for example, a car travelling a distance, or time passing by, but struggle to consolidate these together in a two dimensional graphical representation. For multi-dimensionality of x-y plots, the participants in the DWN group described difficulty in understanding how two increasing values could be related. Research has suggested that dyscalculic students may be able to understand time passing on the x axis, and distance increasing on a y-axis, but find it difficult to conceptualise the relationship between the two in order to recognise a correlation.

As simple graphical representations were generally understood by the participants, it may be possible to incorporate pictograms or bar-charts as a possible intermediary strategy to help dyscalculic students understand more complex graphs. Moritz and Watson (1997) described how the use of pictograms is "particularly important to establish links between actual objects and one-to-one representations of data, prior to more symbolic forms of scaled representation" (p222). If pictograms or other more concrete iconic graphs could be devised as ‘stepping-stones’ that lead to more abstract forms of representation, this could be a way to scaffold dyscalculic students conceptual understanding of increasingly complex graphical representations.

Surprisingly, one statistics topic was described positively. As inferential statistics packages in social science courses tend to be taught from a procedural perspective rather than by understanding the underlying mathematical concepts, the dyscalculic students were able to keep up with (or in one case outperform) their peers.

Standardised units were shown to confuse the participants as they could not relate the values to everyday contextualised examples. This is likely to be the result of a combination of issues with numerosity, iconicity and non-cardinality. Although the participants may have had some understanding of a number value in isolation, the addition of a standardised unit often resulted in the measure acquiring little or no
meaning. In previous literature, numerosity issues and standardised units have not been considered as separate issues, which I feel can be misleading. For example, a dyscalculic individual may not be able to estimate the length of a metre however this is unlikely to be a numerosity issue as the number involved is one. It is more likely to be confusion with knowing what a metre represents. The issue with standardised units is similar to the difficulties with non-cardinal numbers and iconicity, as it adds a layer of abstraction to a number that is not perceivable by visual clues.

Difficulty with telling the time was reported as an issue for many of the participants. The participants in the DYO group expressed a strong preference for digital time, despite its numerical nature, as they struggled to interpret analogue time. Participants in the CDD category preferred the visual nature of this analogue format. The 24-hour clock was unpopular in both groups due to the mathematics involved in conversion to an AM/PM format. Students in the DWN group showed evidence of fundamental conceptual time difficulties that paralleled severe problems with numerosity.

Time was shown to be a strong theme to emerge and provided difficulties both academically and in everyday life. Time management issues could have been predicted, as these involve arithmetic difficulties, made harder by the ‘non base ten’ format of astronomical time, i.e. sixty minutes in an hour.

Another issue highlighted by some of the participants was difficulty perceiving the passage of time, which is unrelated to difficulties with telling the time or performing time calculations. Problems with estimating the passage of time may be linked to the abstract nature of time or the same estimation difficulties as observed with numbers due to the malformation of mental number lines. The perception of the passage of time is also socio-cultural as many of the coping strategies for tackling this difficulty relied on using everyday events with a consistent duration to compensate for this difficulty. This issue has been identified before with other neurodiversities, but there has been no in depth research into the phenomenon that I am aware of. If this difficulty is a characteristic of dyscalculia, then it suggests the same cognitive processes that are used to process number are also involved in the perception of time passing. This is another area in which research could provide further knowledge of dyscalculia and neurodiversity in general, although the study methods required could be difficult to design and implement.

Participants described difficulties with time calculations which led to poor timekeeping. A combination of this and other time issues such as telling the time and perception of time led to poor punctuality, which in turn caused embarrassment, reduced social interaction, and in one case, dismissal from work. The participants recognised that punctuality was a
key socio-cultural skill and therefore several strategies to ensure punctuality were devised. They described an array of coping strategies to aid punctuality, including a highly organised system of alarms and adjustments to lifestyle in order to reduce dependency on the clock. Everyday activities such as smoking a cigarette were used to keep track of time, as well as more extreme measures such as living close to the train station to reduce travel timing issues. These findings have implications for the development of coping strategies for dyscalculic learners.

Finally, in this section I discussed the elements of mathematics that specifically affect students in careers associated with formalised fitness to practise regulation. For healthcare students this covered the use of measuring devices like weighing scales, counting tablets, drug calculations and interpreting graphical data. Simple graphs were shown to be less difficult than may have been predicted as they follow a set pattern and are often demarcated to highlight potential areas of concern. Interpreting medical graphs for many healthcare workers had become procedural rather than relying on comprehension of the underlying data relationships.

For the student teacher in my sample, it was the qualified teacher status (QTS) mathematics exam which caused difficulty. The standard of mathematics required for the test was higher than she would be expected to teach to her early years’ students. This raised discussion about the fairness of the demands on early years’ teachers and on what is an appropriate level of achievement for a teacher to be able to offer pupils appropriate learning experiences.
Chapter 10 – Experiences of learning and support in higher education

10 Experiences of learning and support in higher education

10.1 Introduction

This chapter addresses the third research question:

What are the experiences of learning and support of dyscalculic students in HE?

The initial section examines the preferred learning style, media and environment of dyscalculic students in higher education and the implications for a co-occurring identification of dyslexia. Whilst every student must be considered as an individual with their own strengths and weaknesses, previous research has identified that mathematics learning can be considered within one of two broad approaches, those of conceptual learning and procedural learning (Sharma, 1997; Chinn & Ashcroft, 1998).

Henderson (1998) described that dyslexic learners with mathematical difficulties (MD) displayed characteristics of the conceptual learner, but little research has been undertaken to explore the ways in which dyscalculic students approach the learning of mathematics. This section considers firstly the procedural and conceptual learning styles of dyscalculic students before examining the effect of co-occurring dyslexia on individual preference. Discussion of the influence of learning environment and the students’ preferences for visual or verbal media is then followed by an exploration of the students’ awareness of their own learning needs.

The next section examines reasonable adjustments. These, as discussed in section 5.2, are offered to students with an officially identified specific learning difference (SpLD) to provide non course-specific assistance. Whilst there is agreement about established best practice in terms of reasonable adjustments for dyslexic learners, there has been little research into the most effective adjustments for dyscalculic students. The needs assessment is based upon the EP report but there are few established reasonable adjustments for dyscalculia. Anecdotal evidence suggests that needs assessors tend to follow the dyslexia model when looking for support for dyscalculic students. This section firstly examines the reasonable adjustments offered to participants in my study, and how they were experienced and evaluated. It then explores the examination strategies employed by dyscalculic students, focussing on the most commonly mentioned adjustment for assessment, the allocation of extra time. Finally, it considers the use of calculators as a reasonable adjustment, and questions the validity of their prohibition in some examinations.
The final section examines the importance of one-to-one sessions as a means of supporting dyscalculic students, and explores the elements of these sessions which could be developed into recommendations for practice. Data analysed included observations from support sessions with dyscalculic student Fiona and dyslexic student Ian, (who was observed as a contrast to help me understand the potential differences in learning styles) (see section 10.2.1), in addition to the fourteen participant interviews. One-to-one support from one or more tutors was only available to ten of the participants in my study and this section describes how the nature and quality of that support varied significantly.

Previous research into the support of dyslexic HE students with mathematical difficulties has raised a number of recommendations (Trott, 2003; Perkin & Croft, 2007). These have included breaking up text into smaller ‘chunks’, the use of colour with overlays and pens, flow diagrams and mind mapping software to help organisation, memory strategies such as flash cards and mnemonics and pictorial representations to aid greater understanding. This section examines what support has been offered to dyscalculic students and how it compares to what is known about the support of dyslexia in HE students.

10.2 Academic study

This section examines the academic experience of the participants during HE, focussing on how the dyscalculic students learn mathematics by examining learning styles. It then explores the preferred learning environments and learning media of the participants.

10.2.1 Learning style

For this analysis I have used Chinn and Ashcroft’s (1998) idea of grasshopper and inchworm learning styles (see section 2.3.4). Students who use grasshopper strategies show a better understanding of the underlying mathematics and are referred to as ‘conceptual learners’. A student, who prefers an inchworm strategy of sequential steps, would be described as a ‘procedural’ learner.

In this study I refer to the learning style of each student as either procedural, conceptual, or a combination of attributes from both. All participants in the study reported a learning style that relied heavily on procedural strategies, where method was more important than meaning. For example, when Alison was asked how she addressed mathematical tasks, she repeatedly made reference to a procedural approach:

*I learnt a procedure. I learnt a procedure and...no, yeah... I learnt a procedure (Alison)*
This procedural style required a good memory to compensate for the lack of understanding, as described by Olivia:

It was the repetition... [I] would repeat it over, and over, and over, and over, and over again so that it went from my working memory into my long-term memory. And then, I remembered it. It was fine. I could do it. But it was that repetition of doing it over, and over, and over, and over again. (Olivia)

The procedural learning strategy reported by the participants appeared to differ significantly from what is known about the way dyslexic students are most likely to learn mathematics, which is more conceptual (Henderson, 1998). This difference in learning style could be accounted for by the inherent strengths and weaknesses associated with the respective learning differences.

Students with a co-occurrence of dyscalculia and dyslexia (CDD) appeared to prefer the procedural strategy favoured by the dyscalculia only (DYO) students, with all three members of the group advocating a sequential learning approach. Perhaps surprisingly, the challenges inherent in both dyslexia and dyscalculia, when combined, did not appear to have made learning mathematics twice as difficult for the participants of the CDD group in this study, which was a phenomenon recognised by Landerl et al. (2009).

Dyslexia is associated with a number of specific strengths that the students were able to incorporate into coping strategies, most notably strong visual learning skills as described in section 10.2.3. However, with the exception of a common preferred procedural learning style, the learning profiles of students in the DYO group and those within the CDD group were very different. This would necessitate a different approach to learning support and any reasonable adjustments made by the HEI (see section 10.3.1).

Only one participant, Gemma, in addition to her procedural strategies, described an affinity with a more conceptual learning approach. Like the other participants, she was in favour of using mathematical rules where she could follow pre-prescribed steps, which she particularly associated with algebra:

It's just a rule, and I don't, I mean, all maths is just rules when it comes down to it.... I'd remember all those steps and [once I'd] stopped missing them out or swapping them [numbers] round, I could do it every time. (Gemma)

But unlike the other participants she described some ability to appreciate mathematical topics conceptually, for example in her recollection of negative numbers:
I had this sudden breakthrough as thinking about it [negative numbers] as being closer to the zero, rather than thinking about it as a negative number, because that concept still confuses me. (Gemma)

Gemma was able to conceptualise the modular size of a negative number by its distance from zero on a number line. This helped her understand that minus two (-2) was larger than minus three (-3) as it was closer to zero. Gemma was the only participant who showed an ability to utilise both learning styles. Although she employed strong procedural strategies, she was still trying to conceptually understand the mathematics and described this as her desired method of learning.

Additionally, she was one of only two participants who expressed comfort with both verbal and visual media, as discussed in section 10.2.3. Although Gemma was categorised as being a high achiever (H Ach), she was also the only dyslexic in that group. When initially assigning the participants to the various classifications, I felt that Gemma’s alignment to the H Ach group was stronger than her alignment to the CDD group, even though she was also dyslexic. On reflection, her dyslexia could explain her adaptability between procedural and conceptual learning styles. Further research would be required to establish whether Gemma’s characteristics, unique in this sample, are a common feature of high achieving individuals with a co-occurrence of dyscalculia and dyslexia.

10.2.2 Learning environment

It is widely accepted that dyslexic-only students with mathematical difficulties can benefit from multi-sensory learning, using tangible or visual resources (Hunter-Carsch & Herrington, 2005; Mortimore, 2008). Findings from my study suggest that this is also true for the participants within the CDD group, such as Alison:

The only way I’d understand it [division] was if they [teachers] had the sweets in front of us, actually dividing the class up into the children. (Alison)

For the participants in the dyscalculia only (DYO) group, multi-sensory techniques appeared helpful but not to the same extent. Heather’s experience with multilink blocks, discussed in section 9.2.4.2, suggested that even with the use of a tangible representative object, DYO learners could still struggle to make a connection between abstract mathematical ideas and the social world they inhabit. Evidence from two DYO participants, Heather and Fiona, suggested that DYO students may prefer a learning environment that is less removed from real-life context, an approach I hereafter refer to
as ‘in situ contextualisation’ (see section 10.4.4). Heather repeatedly referred to a lack of contextualisation:

*I just think I’ve never seen a purpose for it [percentages]. It’s never been brought into context for me.* (Heather)

She frequently commented that she could not understand various mathematical concepts because she could not relate them to real life. For Heather, verbal attempts to relate concepts to real-world situations were insufficient to support her learning. In order to relate to mathematical concepts, she needed to experience them in a very practical, ‘hands-on’ way, and to be fully immersed in a relatable, socially relevant activity.

Fiona also had difficulty relating the familiar natural world to the seemingly abstract mathematical concepts of tabulated data and graphical representation as discussed in section 9.5.2.4. During support sessions, she described her frustration that a subject which she thought she understood, such as the quantities of various flora and fauna, had been transformed into something that she found incomprehensible. From a personal perspective I found the classroom environment an impediment to progress when working with Fiona, as her preferred place of study on her Wildlife and Countryside Management course was outdoors. For these reasons, if it had been possible to carry out support sessions within her normal study environment in the natural world, opportunities for learning may have been enhanced. There are parallels between this situation and the issues reported in literature on nurses studying for drug calculation examinations in an academic setting. Hutton (1988) found that outside the clinical environment, healthcare students often struggle to answer theoretical questions that they would have been able to answer in a real-life scenario on the ward.

### 10.2.3 Learning media

A noticeable difference between participants in the co-occurrence of dyscalculia and dyslexia (CDD) and dyscalculia only (DYO) groups was in their preferred media for learning. Although they all reported that they would avoid reading numbers wherever possible, the participants from the DYO group displayed stronger verbal skills and were therefore more likely to acquire information from text than a pictorial representation. Five of the DYO participants described that they needed words to explain new ideas and would just ignore any symbols, formulae or graphs that accompanied the text. Henderson (2012) reported that the interspersion of graphical information amongst text can compromise readability for dyslexic learners. However, this may also be a problem for some DYO learners, as described by Nancy:
If I’m reading a book and there’s a number in the middle of the text I just skim it and then I have to make myself go back and try and understand what that represents and then I can get on with reading again. (Nancy)

The DYO participants in this case appeared to be assuming that the text explanation would be sufficient to convey the desired message. In situations where mathematics could not be avoided, descriptions in words can be used to scaffold the mathematical understanding. Olivia described an occasion, when a lecturer explaining a mathematical topic, chose to use a literary approach rather than just equations:

It’s still slightly strange that I can understand it, probably because it’s explained in words... There was one tutor who would write huge paragraphs about how to do something. Nobody else liked it. They just wanted the formula or whatever. I really liked that, because I was like, “Yeah, this makes sense.” It was all written in words, and then you would have the formula underneath, and then you would have an example... And that made sense to me, because I could read it. (Olivia)

Olivia described the techniques which led to her beginning to understand mathematical concepts for the first time. Although she had become alienated by symbols and numbers, some of what the tutor was explaining in words had registered with Olivia on a conceptual level. This ‘word-based’ approach worked well for most participants in the DYO group. Participants within the CDD group, however, generally preferred a pictorial or visual media for learning. This was associated with the participants developing their own visual memory strategies to aid in remembering equations and procedural methods. Bradley’s strategy was typical:

I made loads of like revision cards and they were all different colours and I could remember quite a lot of them by the end of the year. (Bradley)

Bradley and Alison, both CDD group members, found the use of flash cards helpful to remember mathematical facts. Ellen, also in the CDD group, described the use of formulae triangles as a visual memory aid. This consists of algebraic letters positioned in a triangle to show whether the variables should be divided or multiplied to produce a result. A common example of this is for the formula ‘distance equals speed multiplied by time’:

I understood how to do them [formulae triangles], putting them in those little triangles and I remembered all the equations and how to do it. (Ellen)

These self-developed strategies such as the use of flash cards, use of colour and mind maps, are established as useful tools for dyslexic students learning mathematics in HE (Trott, 2003; Perkin & Croft, 2007).
All but three of the participants in my study described a preference for either a verbal (use of text or spoken words) or visual (use of pictures) approach to learning, as predicted by their dyscalculic category affiliation. For the three students whose preferred learning style was not the one predicted by their group, (Nancy, Gemma and Julie), there are possible explanations for their atypical preferences. Two of the three showed a strong affinity for both verbal and visual learning. For Nancy, this was because she was a dyscalculic-only student who had strong artistic abilities and therefore often displayed the strong visual skills associated with dyslexia. Gemma, a particularly high achieving participant, had developed advanced coping skills that enabled her to use both learning styles. Julie, although not dyslexic, had an identification of visual stress that made reading difficult and she had therefore adopted a pictorial approach to learning.

10.2.4 Preference for routine

Once the participants had learned a method that produced correct results, they were reluctant to update the method, even if they were aware of its inefficiencies. From my learning support sessions I found that when Fiona found a method that provided success, she would continue with this method rather than learn a quicker alternative method, for fear of confusion and the risk of losing the knowledge that she had attained. She felt that additional time was better spent exploring other areas of learning. This preference for routine was best highlighted with examples of participants’ everyday travel arrangements to their HEI. Once a regular bus or train route had been established, some participants organised their lives to repeatedly use the same service. Although this created a degree of inflexibility that on occasion led to social exclusion, it reduced dyscalculia-related stress and gave the students a sense of everyday life accomplishment. This was particularly true for the participants in the highly anxious (HAnx) group, such as Quentin:

*Unfortunately, the way it’s [dyscalculia-related travel difficulties] driven me is to have methods in place... keeping things simple and not changing a lot of things, which have been beneficial, [but] have also got a downside, where it does tend to get stale and it really makes doing new things and meeting new people difficult.* (Quentin)

This routine may not always be the most efficient means of travel, but the participants appeared less inclined to explore alternatives once they had a working solution. For example, Maggie’s tutor discovered that she took a bus to college which followed a circular route, and that Maggie chose to use the same bus to return home, rather than catch the return bus from a different stop. Although Maggie’s option was a significantly longer journey, it was a routine that Maggie had discovered herself and it was viable.
Despite Maggie’s tutor physically showing her the alternative bus stop, Maggie chose to continue with the routine she knew rather than risk a new strategy.

### 10.2.5 Awareness of learning style

Most participants displayed awareness that the procedural approach had enabled them to reach their short-term goals and facilitate their continued academic progression. When Deborah was asked a follow-up question about whether she was content with her preferred procedural learning style, she replied:

>I had to just accept it... you just did that to get through? It was just a hurdle that I had to get up, to jump to get to my goal. (Deborah)

The procedural approach of learning rules and sequential steps without a conceptual understanding had generally been successful in allowing the participants to enter HE, but was now being tested in a more robust and demanding academic environment.

The high achievers (H Ach) appeared more aware than the other participants that a procedural strategy was inflexible and not easily transferrable. Even slight deviation from the learned and practised procedure could be problematic if the student was unable to adapt the rehearsed formulaic method, as described by Deborah:

>So in the exam paper, they’d worded it slightly differently and I couldn't apply what I'd learned off by heart and I couldn't do it then. (Deborah)

Gemma was the participant most aware of the weakness of a procedural approach. Although she used a procedural strategy extensively, she recognised that she was prone to intermixing different methods and forgetting steps due to her poor memory, a feature of her dyslexia. Julie was also wary of performing mathematics procedurally without the deeper knowledge.

>It [mathematics] still didn't make a great deal of sense to me. I kept saying, well, "Why are we doing this?" because I can't see the logic in it. But that side, just treating it as an exercise in having to do it with numbers, she [tutor] did explain how to do it, even if I couldn't get the theory settled inside. (Julie)

The participants in the H Ach group all felt a need to understand the rationale underpinning their methodology, and without this conceptual understanding they reported a sense of discomfort. Further exploration of dyscalculic students’ awareness of the weaknesses of a procedural approach, may provide an interesting insight into their perceptions of mathematics.
Some participants reported that their preferred ways of learning were not generally compatible with the teaching style of their educational institution, as illustrated by Alison:

At uni... you get the information then you have to figure it out by yourself. Whereas at school they give you the information, and then the revision pack and then they test you on it and... they review your test and then you get to do your exam. (Alison)

The traditional ‘chalk and talk’ approach to teaching in HE is not always accessible to students with specific learning differences (Webb, 2011). All the participants described negative emotional feelings as they felt they were unable to grasp the mathematical skills required within their chosen academic communities. The social model of disability, as discussed in section 2.3.2, suggests that society should adapt to be inclusive to those who have differing needs. Most of the participants in this study, however, were unable to find or access appropriate learning resources for their individual needs (see section 10.4.5), a fact which had implications for their social identity as students within HE communities, as discussed in chapter 11.

The procedural strategies chosen by the dyscalculic students had often been successful due to the application of hard work. Three participants in particular described the need to work excessive hours, often late into the night, to make very little progress with mathematical assignments. Several participants referred to a sense of unfairness that they had to study for longer than neurotypical students to achieve the same results:

It’s always very frustrating when you work the hardest, I was always the one revising, always the one writing notes, but never the one getting the good grades. (Alison)

This disparity in effort required for success, between neurotypical and dyscalculic learners concurs with Pollak’s (2005) findings with dyslexic HE students.

### 10.3 Support through reasonable adjustments

This section describes the mathematical reasonable adjustments (RAs) that had been offered to the participants, and whether they were effective.

#### 10.3.1 Reasonable adjustments for study

When students are identified as having an SpLD, they are entitled by law to apply through their disabilities department for reasonable adjustments to allow them to access the same services as neurotypical HE students. The costs of these adjustments are met by a government body or sponsor in the form of a Disabled Students Allowance (DSA).
via the process described in section 5.6. Although reasonable adjustments are determined on an individual needs basis, there is currently no consensus as to what should constitute an effective reasonable adjustment for a dyscalculic learner in HE (see section 5.4). Some students, such as Fiona and Rebecca, were aware of a dearth of guidelines for support relating to dyscalculic students:

> What I found quite amusing was for dyslexia and dyspraxia, there are huge sections; for dyscalculia it was very small indeed. And they [guide authors] said it was the most difficult one to do, because there's just so little. (Rebecca)

The guide referred to here by Rebecca is a guide produced by the Royal College of Nursing (RCN) to advise nurses with dyslexia, dyspraxia or dyscalculia (Cowen, 2010).

In the majority of cases, the reasonable adjustments offered to the participants were similar to those offered to some dyslexic students, including a laptop computer, library and photocopying adjustments, voice activation and mind-mapping software, sometimes one-to-one support and extra time for examinations or course work.

> It's more for like dyslexia, the things they've given me. A bigger keyboard and things like that. (Heather)

The adjustment that was overwhelmingly endorsed by all the students was one-to-one support. As this is such a major topic, it is discussed separately in section 10.4. Beyond one-to-one support the participants talked little about other reasonable adjustments, suggesting that very little support had been offered to them. It is therefore essential for needs assessors to fully understand the differences between dyslexia and dyscalculia in order to offer reasonable adjustments that are suited to the needs of the dyscalculic student.

There was one piece of equipment that a single dyscalculic student thought would be beneficial. Fiona described how she had been offered an audio recorder for her lectures. This allowed her to concentrate on the conceptual understanding of the mathematics during the lecture, and make notes at a later point.

> They [lecturers] don’t stop and wait for you to take notes. They are continuing to talk, so I kind of zone out, take a note and that zone back in again and go “Oh I’ve missed a bit.” (Fiona)

Audio recorders have been shown to be advantageous to dyslexic learners, who take longer to copy notes due to working memory issues, and therefore risk falling behind in lectures (Draffin, 2002). Fiona does not have a co-occurrence of dyslexia, but struggles
with mathematical anxiety, and described how she becomes stressed and loses concentration when she sees numbers during a lecture or presentation.

As soon as it [mathematics] appears on the screen, that’s when I struggle, from that point when it pops up and there’s numbers and symbols, and there’s graphs and there’s this and there’s bars. (Fiona)

No other participants mentioned audio recorders which would suggest that this was not an option they have been offered, considered or had used themselves. Typically the participants did not describe difficulty taking notes in other lectures, only those with mathematical content. Ellen, for example, had a part time job as a note-taker to help other dyslexic students, and she had been complimented for the neatness and accuracy of her notes. When asked whether she would take notes for mathematical subjects she replied that she had refused to provide this service for mathematics, physics and chemistry lectures:

No, I’d refuse them [maths subjects]. But I have had some. I do a [research and design] counselling lecture... So, then I had to write in loads of detail on all this statistical stuff... I was like, "It’s a lot of words and I just have to write them, I don’t need to understand it." Well, actually, “I’m not doing this. I’m not going to be assessed. I just have to write it so that person understands it.” (Ellen)

Ellen was able to transcribe some mathematical notes, although she found this part of her job uncomfortable. Assuming she had transcribed mathematical notes correctly, her ability to perform this task could be because her mathematical anxiety was not as severe as some of the other participants. Alternatively it could be because she was not particularly stressed as the mathematics involved did not belong to her and there was no requirement for her to understand it. However there is no evidence to elaborate on why she was able to perform this task.

Only one dyscalculic student mentioned software that helped them overcome their mathematical difficulties (see section 12.4), but this was not part of a needs assessment but rather an online learning tool purchased and offered to the whole cohort. The lack of any age-appropriate mathematics software being offered to the students again highlights the potential need for greater training of needs assessors, given that there are software packages at varying cost, available to support students with additional mathematical learning needs (see section 5.4). However needs assessors are only allowed to offer software that is part of a governmental approved list.
10.3.2 Extra time in examinations

Extra time is commonly given to dyslexic students in examinations to allow them more time to read and process questions and structure answers. This reasonable adjustment was offered to six participants, including all three students in the co-occurrence of dyscalculia and dyslexia (CDD) group. Two of the three found the extra time helpful to counteract their slower processing time due to dyslexia:

*I just need the extra time to just give me, just time to think about what I’m writing.*

(Alison)

The third, however, Ellen, described how the implementation of the adjustments must take into account the needs of a dyscalculic student even if the reasonable adjustments were allocated due to dyslexia:

*I] have 25% extra time or 10% or something.... But if I had an hour-and-a-half exam, I could never work out how much extra time I had anyway. (Ellen)

The extra time available to Ellen had not been communicated in terms that had meaning to her, so as she was unable to calculate the extra time for herself due to her dyscalculia, she found the situation too stressful and chose not utilise it:

*So, I would end up completing the exam, or trying to complete it, in the normal time... So then, the extra time was wasted, because I couldn’t comprehend how much I had.* (Ellen)

The additional stress that this reasonable adjustment created ironically resulted in Ellen having less useful time in which to complete the exam. The problem that Ellen encountered was not the extra time per se, but the way it was administered in this particular case. Had Ellen been receiving one-to-one support at the time, a learning support tutor could have helped her prepare for the exam and ensured she understood the amount of time she had available. The difficulties faced by dyscalculic students when performing time calculations are discussed further in section 9.4.

Only three of the dyscalculia only (DYO) students were offered extra time, highlighting that this was an area in which the reasonable adjustments offered to dyslexic students and dyscalculic students were different. Participants reported varying opinions on the value of extra time in exams. Fiona was the only non-dyslexic participant who had received this adjustment, and felt that the allowance of extra time had enabled her to implement coping strategies for her mathematical difficulties. Deborah, on the other hand, despite being in the high achievers (H Ach) group, had been unable to develop
strategies for answering questions in her examinations, and therefore the extra time had made no difference:

*Extra time for me wouldn’t make any difference because if I can’t do it I can’t do it. I can’t do it outside time just the same as I can’t do it inside time either. (Deborah)*

For Deborah, the extra time highlighted that she had no conceptual understanding of the mathematical tasks in her examination, such as drug doses, concentrations and statistics. The extra time had not only made no difference, but had actually enhanced her mathematical anxiety as there was more time in the examination where she felt helpless. Therefore extra time can be beneficial to DYO students, but only if they have developed strategies to use this time constructively.

It was sometimes not clear from the data whether the extra time offered to dyscalculic students referred to all exams, or specifically ones with a mathematical element. For Deborah the extra time was only applied to mathematics-based modules, but this may not have been the case in other HE institutions:

*In the practical exams where there is still a written element, we didn’t seem to get extra time. (Deborah)*

The allowance of extra time only for ‘mathematical’ exams does create a subjective decision as to how much mathematical content is required to qualify for the adjustment. Even in non-mathematical exams, a student would need to partition work time proportionally based upon the marks available for each question, a routine task for neurotypical students but highly problematic for a dyscalculic learner. I would therefore argue despite Deborah’s issues, that dyscalculic students should qualify for extra time in all exams, both to remove the resource-consuming task of subjective judgement of mathematical content on behalf of the examiners, and to allow dyscalculic students the time needed to plan their exam strategies (assuming they had been adequately prepared by a learning support tutor).

### 10.3.3 Calculators as a coping strategy

Calculators were discussed extensively by all the participants as a coping strategy for both academic and everyday life. The teacher training skills test (QTS) was the only examination discussed in my study where some restriction on calculators was applied, as for over half the examination tested, no calculator was permitted. Anecdotally other such examinations do exist in HE. Despite her dyscalculia, Heather was given no reasonable adjustment to use a calculator during the mental arithmetic section of the QTS test, and
given the restrictive examination time limits, she described her chances of passing as marginal.

All the participants described how calculators have become a vital tool in the dyscalculic students’ repertoire which allowed them to make progress that otherwise may not be possible. Eleven of the participants described the need to use a calculator for both academic work and daily activities. Deborah was typical when she commented:

_I used to carry a calculator in my pocket all the time, and panic if I didn’t have it._
_(Deborah)_

Most of the participants reported that the curricular requirement during secondary education to perform mental and written arithmetic unaided had previously been a huge barrier to achievement. Once this restriction had been removed during HE years and calculators were permitted, the participants were able to use procedural techniques to process number operations, as illustrated by Maggie:

_I don’t really understand what it [multiplication] is for... I just know I can do it on a calculator._ (Maggie)

Maggie explained that even though she did not understand the meaning of a multiplication sign, with a calculator she was able to produce a correct result by matching the symbols on a mathematics question to the button on a calculator. However if she pressed an incorrect key, she would not be able to recognise that a wildly inaccurate result was impossible. Whilst supporting Fiona, I observed that she was able to use calculators systematically, but only when she could recall the correct operator to use with each problem. Like Fiona, all the participants in the severely dyscalculic (SDY) group had difficulty applying the correct operator to a problem, beyond addition.

_Even during uni with the maths tutor, I was always getting multiplication and division round the wrong way. I sometimes would really struggle with dividing and multiplying._
_I used to get them mixed up all the time._ (Rebecca)

Some students reported feelings of embarrassment when using calculators in group situations. Bradley described how he would secretly use a pocket calculator for performing fabric measurements in his textiles workshops:

_I’ve got to use a calculator still and it’s that embarrassing... and it’s still not changing after all these years._ (Bradley)

Bradley was aware that his neurotypical peers could perform these mental arithmetic tasks routinely, and using a calculator would disclose his difficulties to a community
where he felt his neurodiversity could affect his acceptance. For a small number of participants with disclosure issues, such as Deborah and her medical practice, (see section 9.5.4) the use of calculators was often kept secret. However most participants felt able to openly use calculators and discuss their mathematical difficulties. Issues around disclosure are central to participants’ views on identity and are discussed in sections 11.3.8 and 12.5.

10.4 One-to-one support

As one-to-one support was such a major theme when exploring RAs, this section looks exclusively at the quality and suitability of one-to-one support received by the participants.

10.4.1 Complementary learning style

As discussed in section 10.2.1, the participants appeared to adopt a sequential, procedural learning style which is focussed on methods that produce a correct answer, rather than a conceptual understanding of the topic. Some participants have identified that when tutors have displayed awareness of dyscalculic learning styles and created individualised strategies for support, the intervention has been perceived as much more helpful, as observed by Alison.

> She [tutor] explained it in a way that made me understand a bit more of the numbers and what was happening... she just put it in a different way to everyone else. (Alison)

Alison had been supported by a specialist dyscalculia tutor who had acknowledged her different, individual learning style and was able to adapt learning materials accordingly. Alison was able to recognise that the support she was receiving was substantially different from any help she had received previously, and not only provided effective strategies for passing assessments, but also facilitated some conceptual understanding as well. Whilst it seems reasonable that any tutoring strategy should aim to enhance the conceptual understanding of a topic, student and teacher must work together in partnership to balance the need to achieve short-term goals such as passing an exam, with the development of a greater understanding of the subject matter (Herrington, 2001).

An approach by tutors to match support to the learning style of the participant can be seen as a Vygotskian mediating tool (see section 2.3.1). By designing tasks that relied on a procedural learning style and utilising the participant’s strengths, some tutors have been able to work with dyscalculic students to help them feel more confident about their
mathematical abilities and more willing to explore further areas without fear of failure. This support strategy conforms to Vygotsky’s theories on the zone of proximal development (ZPD) (see section 2.3.1), which describes how support needs to find techniques and resources to bridge the gap between the current level of student development and their full potential. This increased confidence in mathematics may only refer to being able to perform mathematical tasks using a procedural strategy, but from the participants’ perspectives they were able to “do” some mathematical topics which gave a measure of success and helped to raise their self-esteem, as explained by Linda:

\[*I did like algebra. I think it’s because I got it. Well, not really understood it, but I could do it, so I didn’t feel so stupid when I was in maths.* (Linda)\

Linda described being able to follow the rules of algebra, such as simplifying terms, but she did not appear to understand the concepts behind algebra and what the letters represented. This supports the idea that dyscalculic students may perceive mathematics differently to neurotypical learners, which is discussed in section 3.7. Many of the participants described a positive disposition towards a particular mathematics topic when they could accurately produce a correct result, even if they had no understanding of the topic. This viewpoint on what constitutes achievement in mathematics should be supported rather than challenged, to allow dyscalculic students the confidence to develop successful fit-for-purpose coping strategies.

### 10.4.2 Emotional well-being and mathematic anxiety support

All participants recounted at least one negative experience from school where they had been chastised by teachers for being “lazy” or “stupid”. Many also described teachers who they felt had misunderstood their educational differences and attributed their problems to a lack of motivation (see section 8.5.2). Each of the eight participants who felt they had received good one-to-one support discussed tutors who had considered their emotional needs as well as their mathematical requirements. This was typified by Julie who felt it was important that her neurodiversity was understood:

\[*She was very good, but also the one-to-one, the fact that there was somebody there who realised that I’d got a problem and wasn’t going to treat me like an idiot.* (Julie)\

McGahey and Szumko (2006) observed that there is common ground between the objectives of a specialist specific learning difference (SpLD) tutor and a counsellor. Having a tutor who was patient and considerate was well evaluated by the participants. For Maggie in particular, this sense of empathy was particularly important as poor past experiences had created a severe phobia of teachers:
When I first went to see her, I really didn’t want to speak to her. I would rather have just been sat in a classroom just doing nothing, than with a teacher when she could watch me all the time, see what I was doing and see when I got it wrong. (Maggie)

All participants from my sample recounted negative classroom experiences that affected their feelings about teachers or mathematics. Maggie, in the severely dyscalculic (SDY) group, was so embarrassed about her mathematics difficulties that she would become highly stressed if she felt a teacher was watching her work. She talked at length about how having a tutor she could trust was imperative to her:

She won’t get cross or frustrated with me, or if she does, she doesn’t show it. And that’s really what I want – just to be able to try without the teachers’ reactions affecting me. (Maggie)

Quentin similarly described how he was unable to build a trusting relationship with his school teachers due to high levels of anxiety:

This underlying anxiety problem seems to feed a lot of things. So, that also affected... relationships with authority figures (Quentin)

In both of these cases, the barriers to establishing a relationship between student and teacher would need to be addressed before any mathematical learning could begin. The ability of the tutor to understand these issues and the emotional needs of the student is then an important foundation for the learning support process. These findings are consistent with existing recommendations for best practice in dyslexia support, which aims to repair relationships between student and teacher by helping students improve their own self esteem, and teachers to better understand SpLDs (Humphrey, 2003; Riddick, 2009).

10.4.3 Language and symbols

Confusion with the use of language in communicating mathematical concepts was raised as an important issue by half the participants. Many dyscalculic students describe limited understanding of fundamental mathematics terminology, with words such as ‘multiplication’ and ‘fractions’ having little meaning. More complex and advanced terminology therefore is often completely inaccessible and causes significant anxiety. Trott (2011a) observed a dyscalculic student who confused the terms ‘row’ and ‘column’, causing difficulties with extracting data from tables. Montis (2000) described how a dyscalculic student with a co-occurrence of dyslexia phonologically confused number phrases such as “five, fifteen, fifty, and fifths” (p549).
The language of mathematics was reported to be an issue by some participants in my study. This was particularly evident for participants in the co-occurrence of dyscalculia and dyslexia (CDD) group, such as Alison:

*I was like “Another maths teacher?”, because I find that they're too intelligent to sometimes explain it to someone with it [dyscalculia]... I really just couldn't understand anything and they were trying to explain it to me... it was like they were talking a different language.* (Alison)

The CDD group participants’ greater difficulties with the use of mathematical terms did not appear to be due to phonological problems, but rather dyslexia-related issues in remembering the definition of words with no conceptual connotation, as typified by Ellen. She described how vocabulary associated with statistics was particularly challenging to her:

*There are certain rules that seem to be introduced ... Like dependent and independent variables and all that. That’s when I got lost.* (Ellen)

Ellen was trying to procedurally remember the terms “dependent” and “independent” and their association with line graphs, which was consistent with the way that dyscalculic students are able to recall the language of mathematics as part of a process, but without the inherent meaning. However, her dyslexia made the memorising of these meaningless terms more difficult.

Section 10.2.3 described how students in the dyscalculia only (DYO) group prefer to learn mathematics verbally, rather than with Arabic numerals or symbols, and how these words must be accessible and not mathematical terms that may confuse them. It is therefore important that the tutor explores alternative ways to describe mathematical constructs. These mathematical explanations should not be intimidating and need to be strongly rooted within everyday experiences, to match the dyscalculic students’ affinity for contextualisation, as discussed in section 10.4.4. This difficulty with mathematical language is not just confined to words, but to symbols as well:

*I think it’s because they [mathematical symbols] don't immediately mean anything, I just have a tendency to not read them. Especially the sort of more complex symbols, if you can call them that. We use a lot of Greek letters.* (Gemma)

Gemma, a participant in the high achievers (H Ach) group, needed to use complex symbols as part of her HE course. Symbols can be even more problematic than language for reasons of iconicity as described in section 9.5.2.1. Symbols are likely to have low iconicity and be pictorially unrepresentative of their meaning. The dyscalculic student
may therefore find it difficult to understand the related mathematical concept, and in addition may struggle to remember the symbol that represents it. The use of alternative symbols to attempt to convey a greater sense of meaning was explored by Trott (2011b) in a case study of a dyscalculic student dealing with complicated formulae. She found that replacing the symbols in formulae with alternative more iconic symbols was helpful for remembering meaning for example using a picture of a square rather than the digit two to represent ‘squared’.

10.4.4 In-situ contextualisation and use of manipulatives

Research has suggested that students with severe mathematical difficulties who struggle with teaching styles aimed at neurotypical learners, could benefit from the use of manipulatives (Chinn, 2013). This was found to be true for five of the participants in this study, most notably those within the CDD group, such as Alison:

*She [tutor] either used props or examples, she would always have teacups on the table and make sure I was active and that I could touch and move things. (Alison)*

The use of manipulatives by a tutor was described favourably by all the visual learners in the sample. For dyslexic Maggie, the use of tangible aids was central to her finding any understanding of new concepts:

*At secondary school... we just had it in front of us on a load of paper or in a textbook, and they just said, "Do it..." But with [dyscalculia support tutor]... We have these sticks. We have cubes and sticks, and pipe cleaners, and stuff and we will just do it like that. (Maggie)*

For Maggie, the manipulatives not only provided a kinaesthetic way of learning, but afforded a sense of security. Maggie was more able to concentrate when she could experience mathematical concepts in a practical, hands-on way, and was far more relaxed and less prone to mathematical anxiety. There was inconsistent evidence however that manipulatives aided the DYO students. Whilst some participants in this group felt they were helpful, others felt there was no benefit (see section 9.2.4.2). This may be because manipulatives are a tool for improving conceptual learning, which matches the preferred learning style of dyslexic learners. As DYO students may be seeking procedural methods to perform mathematical tasks, it is possible that manipulatives may not be as useful as for the students with a co-occurrence of dyscalculia and dyslexia. However there is little data to make a generalisation. Another possible reason for this disparity is that although manipulatives provide a tangible multi-sensory dimension to learning, they are still abstract. Discussion around participants’ opinions on in situ contextualisation and iconicity have shown that participants in the
DYO group struggled with abstract concepts and needed to develop through learning in a culturally relevant environment.

10.4.5 Availability of one-to-one dyscalculia support tutors

Only six participants felt they had received appropriate one-to-one support within HE, and of these, just three had received this support from a dyscalculia specialist. Of the remaining three, two were mathematics tutors and one was a PhD student. Two students were offered one-to-one support but chose not to accept it, citing a lack of time available to attend. Three of the participants described receiving mathematics support from qualified SpLD tutors who, although supportive, did not have the necessary level of mathematical expertise to support the student’s learning for their particular course, as described by Maggie:

[I had a] dyslexia and basic skills tutor, and she did a bit with me. But there was only so much she could do, because she wasn't a maths person. (Maggie)

Maggie’s account shows the importance of learning support tutors understanding both the nature of dyscalculia and the associated issues such as mathematical anxiety and emotional well-being. Although her first tutor was able to help her relax and overcome her phobia of teachers, she was unable to support her mathematical needs. For the participants in the H Ach group, the expected level of mathematics was sometimes beyond a tutor with secondary level mathematical skills. For example, Gemma had been offered support from an external agency secondary mathematics tutor who was not familiar with the topics required for a degree course:

My tutor and tuition companies don't really have an understanding of one, dyscalculia and two, science courses. (Gemma)

The three remaining students reported they were never offered one-to-one mathematics support due to the lack of availability of dyscalculia or mathematics tutors. For Fiona, this was a source of resentment as she felt her right to adequate support had been denied by her HEI due to the lack of dyscalculia awareness in the general HE learning support system.

Heather gave an example of how indiscriminate socially shared learning was not suitable for her when she recounted an invitation to a self-help group where students were encouraged to support each other through their mathematical difficulties:

I went there [to a support session], and they were like "Okay right. You're going to get into groups and every week you're going to meet with this group and discuss your
problems.” And I was like “So you [tutor] are not even going to be there?” So I don’t go, because it’s just other people panicking about things and I don’t want other people telling me things and they don’t know how to do it. (Heather)

Heather felt strongly that this type of support was not appropriate for her needs. She not only doubted the validity of the information that would be shared, but also whether her individualised learning style could be supported in a group environment. As Heather was the only participant to be offered organised peer shared learning, it was unclear whether her dissatisfaction was due to her high levels of anxiety or whether this may also be true for other dyscalculic students.

10.5 Summary and discussion

The data provided insight into how dyscalculic students prefer to learn mathematics, the specific difficulties they faced in HE, and what support had so far been made available. The preferred learning methods of dyscalculic students in the study were shown to follow a pattern which differentiated between two profiles: dyscalculic students with a co-occurrence of dyslexia and students who were dyscalculic-only. The learning methods described by the participants could also be subdivided into three areas: learning style, learning media and learning environment. Learning style covers the cognitive strategy for reaching new knowledge outcomes. Learning media is the transmission media with which learning is best achieved. Learning environment describes how the physical location of the student can affect learning. Table 15 shows a summary of how these learning methods varied between neurodiversity profiles.

<table>
<thead>
<tr>
<th>Learning method</th>
<th>Dyscalculia only</th>
<th>Co-occurrence of dyscalculia and dyslexia</th>
<th>High achiever and co-occurrence of dyscalculia and dyslexia</th>
<th>Dyslexia only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning style</td>
<td>Procedural</td>
<td>Procedural</td>
<td>Conceptual and Procedural</td>
<td>Conceptual</td>
</tr>
<tr>
<td>Learning media</td>
<td>Verbal</td>
<td>Visual</td>
<td>Verbal and Visual</td>
<td>Visual</td>
</tr>
<tr>
<td>Learning environment</td>
<td>In situ contextuaiisation</td>
<td>Tangible</td>
<td>Unknown</td>
<td>Tangible</td>
</tr>
</tbody>
</table>

Table 15 – Preferred learning methods
One student, Gemma, did demonstrate conflicting learning preferences which could be due to her being both a HAch and dyslexic as well as dyscalculic. As she was the only student with this profile, more research would need to be undertaken to establish the validity of this speculation as to why she did not follow a similar pattern to other participants.

The preferred learning style of all the dyscalculic students in my study was found to be procedural, sequential learning, in contrast to that of dyslexic students with mathematics difficulties (MD), which previous research has shown prefer a more holistic approach. This difference in mathematical strategies can be described using Chinn and Ashcroft’s (1998) model of grasshoppers and inchworms. One important finding was that the participants with a co-occurrence of dyslexia also described a preference for procedural strategies, although with other learning methods they tended to follow a pattern in keeping with dyslexic-only learners.

Research into dyslexia has established that dyslexic students with MD often have working memory issues (see section 4.3.1) and this was reinforced in my support sessions with Ian described in section 7.7.1. Trott (2003) reported that issues with working memory can lead to problems retaining mathematical knowledge over time without the use of specific memory aids. In addition, Trott observed that dyslexic students sometimes struggle to present work neatly and logically due to poor organisational skills, leading to errors in procedural methods, as illustrated by the broken line in the dyslexia box in figure 23.

![Figure 23 - Learning style differences between dyslexic and dyscalculic students](image)
For example, dyslexic students may struggle with a column procedure for subtracting numbers due to misaligning digits or forgetting to carry the one. Many dyslexic learners prefer to think holistically (see section 4.3.1), and would be described as ‘grasshopper’ learners due to their ability to deduce the correct answer without any sense of how they came to that result (illustrated by the solid line on the dyslexia section of figure 23).

The disadvantage of this conceptual approach is the inherent difficulty in documenting the mathematical process and showing how the result has been obtained (Henderson & Miles, 2001). For dyscalculic students, who have a fundamental difficulty with the conceptual pathway, procedural, inchworm methods are more likely to result in success, as shown in the dyscalculia section of figure 23. Whilst it may be possible for the dyscalculic learner to achieve conceptual understanding, the process would be slow and require considerable scaffolding (see section 2.3.1). The procedural route bypasses the difficulties of conceptualising numbers and allows dyscalculic students to incorporate their learning strengths, such as verbal skills, organisation or memory. Whilst this does not mean that all dyslexic students with MD are grasshoppers or that all dyscalculic students are inchworms, there appears to be a preference of learning style for each neurodiversity.

For the learning media ‘method’, the strategy of using words to convey mathematical ideas is inefficient for a neurotypical learner due to the inherent ambiguity of language over mathematical symbols, but for the participants appeared to be a useful approach to overcome the meaningless nature of symbols. This could consequently reduce some of the associated mathematical anxiety. Students in the dyscalculia only (DYO) category showed a preference for text-based information, which appeared to be the most effective medium for the promotion of mathematical understanding. In contrast the co-occurrence of dyscalculia and dyslexia (CDD) participants also differed to DYO participants in their preferred learning media, relying on pictorial representations to comprehend facts. Strong visualisation skills are known to be a common feature of dyslexia (see section 4.3.1) and it was unsurprising that the participants within the CDD group described a preference for visually based learning.

Participants within the CDD group demonstrated differences in other aspects of learning style, preferring visual or tangible representations to convey mathematical ideas. Students in the DYO group reported some benefit from a multisensory approach, but appeared to find mathematical learning most effective when embedded within its natural context with minimal abstraction, a process referred to in this thesis as ‘in situ contextualisation’. Both groups reported optimal progress when their learning took place.
within their preferred environment. It is acknowledged that logistical issues may make this impractical in many HEIs.

Many SpLD specialist tutors have described connections between dyslexia and artistic creativity (Wolff & Lundberg, 2002), and this has been supported by case studies of unusually talented dyslexic people (West, 1997). A tendency in dyslexic individuals to be creative and insightful may contribute to the significant number of dyslexic students enrolled on Arts courses (Wolff & Lundberg, 2002). Von Karolyi et al. (2003) observed that dyslexia is associated with well developed visual-spatial abilities, which Chakravarty (2009) suggested is an enhanced ability to process visual-spatial information holistically. The need for a dyscalculic learner to study within a real life context has been suggested by the ideas of in situ contextualisation (see section 10.4.4) and iconicity (see section 9.5.2.1). This is analogous to Carraher et al.’s (1985) seminal paper findings that street sellers in Brazil were able to perform complex mathematics within their socio-cultural setting that they were unable to perform in the classroom. It suggests that teaching and support should do more to remove abstraction from mathematical learning and place the learning of mathematics within a relevant applicable context.

The discovery of these preferred learning methods, and their relationship to a definable dyscalculic profile could have a profound effect on teaching, specifically one-to-one support which can be ‘tweaked’ to the specific individualised needs of the student. One-to-one support was overwhelmingly endorsed by the dyscalculic students in my study as the most effective reasonable adjustment. The participants who had received one-to-one support described how this had been most beneficial when the tutor attempted to match ‘scaffolding’ to the preferred procedural learning style of the student. Before any effective mathematical support can be given, however, the emotional well-being of the student needs to be considered. Factors such as difficulties within daily life may initially affect the student’s receptiveness to support. Measures to address and reduce these issues may therefore enhance the effectiveness of the support received. Numeracy problems in everyday life were described as equally debilitating, in a more negative way than had been seen in dyslexic-only students. A tutor would therefore need to account for the emotional well-being of the dyscalculic student who may be struggling with dyscalculia-related issues that are affecting their ability to concentrate on their studies. One specific area of emotional well-being that needs particular attention, considering existing research (see section 4.4) and participant comments (see section 8.4), is mathematical anxiety (MA). All the participants described severe stress at some point in their lives with regard to mathematics. Four students, however, described how one-to-one support helped them reduce their anxiety and go on to achieve success. As MA is
known to affect working memory (Ashcraft & Kirk, 2001) it could cause a profound disruption to procedural strategies that rely heavily on memory.

Figure 24 shows how MA can affect the procedural learning style preferred by dyscalculic students. Mathematical anxiety may also be a negative experience for dyslexic students, but their holistic, conceptual learning style relies less on working memory and therefore is likely to be less affected by MA. Dyslexia is known to impact working memory (see section 4.3.1) so procedural strategies are less important to dyslexics’ preferred learning methods. By reducing mathematical anxiety, the dyscalculic student could potentially ‘free up’ working memory and be better able to utilise their preferred procedural learning style. Arem (2002) suggested a number of interventions to help students overcome MA. These strategies involved improving working memory, overcoming internal barriers, positive thinking, finding tools for visualising mathematics, understanding individualised learning styles and overcoming test anxiety. Maloney and Beilock (2012) pioneered a technique of asking students to express their anxiety feelings to a tutor or supportive other roughly fifteen minutes before facing a mathematical assessment, a strategy designed to alleviate the burden of negative emotions on working memory.

Another area where a one-to-one tutor could be effective, is in limiting the use of mathematical language. The translation of mathematical terms and symbols into less specialist terms and phrases can allow for greater understanding, particularly with dyscalculic-only students. Manipulatives were shown to be highly beneficial to dyscalculic students with a co-occurrence of dyslexia or those with a visual learning style, but amongst the remaining students their usefulness remains unclear.
Lack of specialist dyscalculia tutors was cited as a concern, with most students receiving support from tutors qualified in supporting students with other SpLDs or those with a minimal mathematics background. Three participants were offered no one-to-one support, despite this being a recommendation in their needs assessment. All participants who had received appropriate one-to-one support from a tutor qualified in dyscalculia and HE mathematics had gone on to have success by achieving good grades in HE.

Where the tutor had knowledge of either SpLDs or HE mathematics, but not both, the results were mixed, but still generally positively evaluated. The largest concern relating to one-to-one support was availability, with many of the dyscalculic students reporting that their HEI was unable to provide suitable one-to-one support.

The data showed that the reasonable adjustments offered to dyscalculic students appeared similar to those given to dyslexic students, which most participants felt offered little practical benefit beyond one-to-one support. The allocation of extra time was the next most commonly mentioned reasonable adjustment after one-to-one support. It has already been established that extra time is beneficial for dyslexic students, but for the dyscalculic-only students in my study the experience of this provision was varied. Most participants appreciated the benefit of extra time, however two participants found that it had not been useful. Extra time in examinations was described as being beneficial only when the dyscalculic student had spent time working with a tutor developing strategies to use the extra time constructively. I suggest that extra time should be granted for all examinations, not just those with mathematical content, as the process of allocating appropriate time limits to questions according to mark value is intrinsically a mathematical task.

The use of calculators was discussed, although there is no consensus on whether they should be universally accepted as a reasonable adjustment in all examination settings. There was only one example in my study where the use of calculators was prohibited, although anecdotally other non-calculator examinations do exist in HE. Calculators should also be allowed for all examinations. Audio records of lectures and mathematics software were two potential reasonable adjustments that could be beneficial but currently do not appear to be offered by needs assessors with any regularity.
Chapter 12 – Fitness to practise

11 Categorisation of dyscalculic students in higher education

11.1 Introduction

This chapter addresses the fourth research question:

*Are there different categories of dyscalculic HE students?*

I have utilised two separate approaches to explore the idea of categories of dyscalculic HE student. Firstly by analysing the thematic codes produced by my grounded theory methodology, I was able to identify that the participants could be grouped into five separate categories that demonstrated varying dyscalculic attributes. This analysis is explored in detail in section 7.6, and the categories have been used throughout chapters eight to ten as a framework to compare and contrast the participants’ narratives. This categorisation model is printed in table 16 as a reminder and is referred to as the Grounded model to distinguish it from my other alternative approach. For the second method I have adopted Pollak’s (2002) model for dyslexic HE learners as a framework, which is outlined in section 2.3.3. By categorising the participants using the categories proposed by Pollak, I have been able to identify some potential differences in how dyscalculic and dyslexic students view their social world and sense of self-worth. From this, I have created a new model that reflects the differences between dyscalculic HE students, which I refer to as the Adapted Pollak model.

The next section explores the factors that have informed the participants’ views on dyscalculia. Some of these social factors have already been described in section 8.2 as they are also reasons for choosing to enter HE and many of the contributing factors have originated from childhood experiences. As the identification of dyscalculia occurred in adulthood for all participants in this study, they generally described a well established identity formed from early experiences, prior to identification. The themes discussed below appear to be influencing factors in a participant adopting a particular dyscalculia categorisation. There is evidence of some changes of categorisation in response to identification, however exploration of the longer term, post-identification effects on categorisation was not possible from this study.

I discuss how these two models relate to each other and find a strong mapping between them based upon participant alignment and social factors that influence the development of the participants’ categorisations. It should be remembered when making comparisons between Pollak’s study and my own, that his research was based upon a thematic discourse analysis, aimed exclusively at cataloguing word usage when dyslexic students
described their difficulties. My study, as an analysis of the participant narrative, had a wider scope, and therefore does not analyse discourse alone or in the same depth as a means of categorisation.

<table>
<thead>
<tr>
<th>Grounded model</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dyscalculia with numerosity issues</strong></td>
<td>DWN</td>
<td>Fundamental numerosity and subitising issues associated with the Butterworth model of dyscalculia (section 3.6). Participants in this group were the most severely dyscalculic in the sample.</td>
</tr>
<tr>
<td><strong>Dyscalculia without numerosity issues</strong></td>
<td>DWO</td>
<td>Identified as dyscalculic due to the discrepancy model (see section 3.3.1.4). Severe mathematical weakness, but did not show evidence of the most fundamental issues with numerosity.</td>
</tr>
<tr>
<td><strong>High achievers</strong></td>
<td>HAch</td>
<td>Achievement of academic success that may be surprising, given their dyscalculia. Includes mature students who had already enjoyed a successful career, and students who were enrolled on courses that may be considered too mathematically demanding for other dyscalculic students by their parents, peers or teachers. They had been identified using the discrepancy model (see section 3.3.1.4), but their mathematical ability was considered poor only in contrast to their exceptionally high general intelligence.</td>
</tr>
<tr>
<td><strong>Highly anxious</strong></td>
<td>HAnx</td>
<td>The display of high levels of either mathematics-related or general anxiety. This anxiety was in excess of the mathematical anxiety expected of dyscalculic individuals.</td>
</tr>
<tr>
<td><strong>Co-occurrence of dyscalculia and dyslexia</strong></td>
<td>CDD</td>
<td>Identified as being dyslexic, but able to use positive characteristics of dyslexia to develop strategies to cope with dyscalculia.</td>
</tr>
</tbody>
</table>

Table 16 – Grounded model of dyscalculic HE categorisations

### 11.2 Adapted Pollak model

Pollak (2002), observed five types of discourse in dyslexic HE students. He categorised these as *patient*, *student*, *hemispherist*, *syndromist* and *campaigner*. A full description of these categories can be found in section 2.3.3. I have used this model as a template to explore whether the participants in my study displayed similar characteristics.
11.2.1 Patient category

In Pollak’s (2002) model he classified dyslexic students who viewed themselves as having a ‘medical condition’ as patient. This type of personal reflection could be seen as embedded in Oliver’s (1990) medical model and is where the participant considers him or herself primarily to be an individual with a neurodiversity. This category was observed far less frequently in my study than in Pollak’s.

Quentin was one of only two participants in my sample who showed evidence of aligning to patient:

*It’s just really since I started thinking about this dyscalculia, it really has hit home how much it not only defines but directs my choices in life. As I say, things like [not] driving, things like going on holiday, travelling, making arrangements to meet people, so socialising, even trying to be ambitious and get a better job.* (Quentin)

Quentin talked at length about how dyscalculia was the reason for his difficulties, and mentioned the term dyscalculia more than twice as many times as any other participant. His general anxiety was also his most dominant characteristic and defined his perspective on life issues. Quentin therefore saw himself as a patient, not just because of his dyscalculia, but also because of his wider lifelong mental health difficulties.

Heather was another participant who could be considered as having a patient viewpoint. As well as experiencing similar anxiety issues to Quentin, she also had a belief that her dyscalculia may actually be acalculia (dyscalculic characteristics caused by trauma) due to a childhood accident:

*I was talking to my doctor about this, and when I was a baby I fractured my skull, and he thinks that could be something to do with it, it could have damaged that part of my brain or anything.* (Heather)

Although it would be impossible to determine whether her mathematical difficulties were developmental or accidental, the possibility had influenced Heather towards a medical interpretation of her difficulties.

There was, however, less evidence of the patient category from the other participants, who were more inclined to adopt the syndromist viewpoint (see section 11.2.2) and align themselves with a set of mathematical difficulties, rather than a neurodiversity label. This was not in keeping with Pollak’s (2002) findings with dyslexic HE students, where patient was the most common category. I had initially assumed it may be because Pollak’s participants had been identified much earlier than the dyscalculic students in my
study. However, a closer examination of Pollak’s data showed an equally large number of participants who were identified during HE. Although dyslexia across the whole educational timeframe is identified earlier on average than dyscalculia (see section 4.3.1), many dyslexic students are still identified during HE (Singleton, 1999; Pavey, 2009). This may be because schools are not well equipped to identify SpLDs, or that very able dyslexic and dyscalculic students are able to manage the demands of secondary education and are only identified in HE when their existing coping strategies are no longer adequate for the additional academic pressure.

I suggest two possible reasons for the difference in prevalence of patient category between the two studies: those of memory issues and stigmatisation. Before being identified with a neurodiversity, dyslexic individuals would probably have been aware that they had significant memory issues, which Pollak suggested they may perceive as a medical problem. Therefore, Pollak felt that they should be included in the patient category. Dyscalculia does not have a synonymous ‘medical’ characteristic with which individuals can associate before the identification of their neurodiversity. Participants in my study therefore only identified with being a patient due to wider well-being issues outside their dyscalculia.

The category of patient can also be the result of feelings of stigmatisation. Ingesson (2007) claimed that stigmatisation can occur in some cultures where there is limited awareness and acceptance of SpLDs. Pollak’s nine patients included four international students. In a vignette from Pollak’s study, a French student described how dyslexia was a stigmatisation that would affect her chances of progress in a future career. There were no international students in my sample, but in a rejected interview (see section 7.4.1), Greek student Christophe raised stigmatisation as a major concern. It is possible that if my sample had included dyscalculic students from different cultural backgrounds, the prevalence of the patient category may have been higher. In my study, stigmatisation was raised in the context of fitness to practise, as the participants in the health and teaching professions discussed concerns that an identification of dyscalculia may inhibit their career opportunities, as discussed in section 12.5. However, each of these participants showed a stronger alignment to categories other than patient.

11.2.2 Syndromist category

The syndromist category describes individuals who form a perspective based upon their cognitive weaknesses with mathematics. Syndromist dyscalculic students appeared to have the strongest association as ‘someone who struggles severely with mathematics’. Three of the participants in my study could be described as syndromist. As the
identification of dyscalculia had been a recent event, the participants had already spent many years associating themselves with a set of mathematical difficulties across differing aspects of their education and everyday lives. Nancy was typical when she described her sense of frustration at being a poor mathematician:

*I think I do give a really good show at giving it [mathematics] a go, but I know, when I'm honest with myself in the back of my head, I'm just going "I can't do this. This is pointless", so I'll try and pay attention and learn and take it in, but, at the same time, I'm going "Why are you even bothering?"* (Nancy)

The feelings expressed by Nancy were common in the narratives, where dyscalculic students associated themselves with their struggles to perform mathematical tasks, and described the futility of continuing to try.

### 11.2.3 Heterogenist category

As both positive and negative characteristics of dyslexia are strongly associated with specific hemispheres of the brain, Pollak (2002) coined the term *hemispherist* to describe a student who acknowledges both the strengths and weaknesses that can be attributed to dyslexia. The hemisphere model however is not applicable to dyscalculia, as the areas of the brain linked to dyscalculia have been identified in both hemispheres (see appendix M). Dyscalculic-only students often have good verbal skills in the same way that dyslexic individuals are often creative or have strong visual acuity (see section 10.2.3). The participants in my study described an array of individualised strengths that some were able to incorporate into a balanced assessment of their self-worth. I have therefore renamed the category to *heterogenist* to describe a learner who identifies with both the strengths and weakness of their neurodiversity.

Three participants described the recognition of talents that countered their mathematical difficulties and enabled them to achieve targets that others thought were impossible. These strengths were strongly linked to the dyscalculic students’ coping strategies, and where the participant was fully aware of their self-developed coping mechanisms, this led to the *heterogenist* category. For example, Alison had created a coping strategy based around her exceptional visual memory skills and was proud and vocal about her learning strengths:

*I think I've got a good memory... So I just remember everything, and when I learn I can sit and see a piece of paper and then I know where everything is on the piece of paper, if I'm in the exam I know sheet three that I had written about small business issues, I know it was the third point in that and I can see it all written out.* (Alison)
The tone of her narrative was more confident than many of the other participants, and there was a greater sense of balance between the difficulties encountered and her accomplishments through her successful coping strategies.

11.2.4 Campaigner category

The category of campaigner can be associated with participants who were frustrated by perceived unfairness of learning support and legislative systems, and were proactive in trying to change the system to meet their needs. These grievances were sometimes directed against the failure of the education system to identify them at an earlier age, or the lack of support that they received throughout their education. There were three participants who aligned closely to this type. For Rebecca, the injustice was the lack of identification:

*I think what also bugged me was the fact that it took so long to get me diagnosed, and I think then it was starting to realise that I was failed so much by the system, and I think that's what really annoyed me.* (Rebecca)

Fiona was the participant with the strongest campaigner alignment:

*There’s nobody in my county who is a dyscalculia specialist, because everybody is geared to dyslexia. There’s a maths drop-in clinic at the university, which I will visit. I did speak to the guy the other day, briefly, and said, I have this problem and he’s like, "Oh, fine. Just come along" but I don’t know whether he will have the skills to deal with my problems.* (Fiona)

Her discontent was with the lack of support available after identification, which she felt she had a right to expect.

11.2.5 Vocationalist category

Pollak’s (2002) original identity category of student described learners who view their neurodiversity only in terms of education, and see it as separate to other aspects of their lives. This was rarely true of the participants in my study, as the mathematical difficulties associated with dyscalculia were not confined to education, but were also highly prevalent in everyday life. Only Gemma could be identified as a student as defined by Pollak’s taxonomy, as her mathematical skills were stronger than the other participants and her everyday life difficulties were not so pronounced. She defined herself by the way her mathematical abilities did not match her other intellectual capabilities, putting at risk her chosen degree:
[Mathematics] is not at the same level as everything else and that is a big difference for me. But in comparison to the general population, it's probably not as bad as it feels in purely a statistical sense. Like maybe possibly a little bit below average maybe average. And you think "Well it doesn't sound too bad" but then because you expect to be right at the top it feels a big difference, you see. (Gemma)

There were a number of participants in the study who did not closely align to any of Pollak’s five categories. These were career-focussed individuals who had chosen courses that led directly into a fixed professional path. These participants described dyscalculia as having had a major effect on their careers, most notably with fitness to practise issues (see chapter 12). I have expanded Pollak’s original definition of student to also include the chosen profession of the dyscalculic student and renamed this category vocationalist. For example, when Julie studied Law, she had to pass a mandatory Accountancy course, which caused her great difficulty and stress:

I subsequently did a law degree and became a lawyer, solicitor. I had to do an Accountancy course to qualify as a lawyer, and that is treated as almost the major part of the professional qualification... And if you fail the Accountancy course you fail the whole lot, whereas if you failed, say, Criminal Law, you just re-sat the paper. I've never understood the logic behind it. (Julie)

The same feelings of commitment to a chosen profession were displayed by Deborah, studying medicine. The two participants’ reflections on dyscalculia were framed by its detrimental effects on their chances of reaching their career goals. With the vocationalist participants, there was much less discussion about the wider issues of dyscalculia than with other participants in the study.

11.2.6 Overview of the Adapted Pollak model

The new model (see figure 25) contains the same number of categories as Pollak’s dyslexia model; three remain unchanged (patient, syndromist, campaigner) and a fourth, heterogenist, has the same concept as the Pollak type hemispherist, with the name changed to be more reflective of dyscalculia. The fifth category, vocationalist, is an expansion of Pollak’s student category to include students who identify themselves strongly with a chosen career path.

In Pollak’s original model, the size of the boxes relates to the proportion of participants aligned to a particular category, and I have adopted this approach within mine, although a larger sample would be required for quantitative comparative analysis. The frequency of patient appeared to be much smaller for dyscalculic than dyslexic students. The syndromist, a category proposed by Pollak but with which he found no aligned
individuals, appeared to be the most commonly occurring category for the dyscalculic HE students.

The arrows in the figure refer to possible transitions from one category to another (see sections 11.2.7 and 11.4.2). Both patient and syndromist categories can be described as grounded in the medical model, as they reflect on negative characteristics that define an individual as having a medical condition. In figure 25 these are represented by a light-coloured background.

<table>
<thead>
<tr>
<th>Theory</th>
<th>Category</th>
<th>Participant</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical model</td>
<td>Patient</td>
<td>Quentin</td>
<td>Severe general anxiety and mental health issues.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heather</td>
<td>Severe mathematical anxiety and a belief that</td>
</tr>
</tbody>
</table>
mathematical difficulties may be acalculia.

<table>
<thead>
<tr>
<th>Syndromist</th>
<th>Linda</th>
<th>Severe mathematical difficulties relating to counting, subitising and numerosity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maggie</td>
<td></td>
<td>Severe mathematical difficulties relating to numerosity, the standardisation of measurement units and the concept of time.</td>
</tr>
<tr>
<td>Nancy</td>
<td></td>
<td>Significant mathematical difficulties including issues with counting and numerosity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social model</th>
<th>Campaigner</th>
<th>Fiona</th>
<th>Feelings of injustice at not receiving the one-to-one to support she was entitled to.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Olivia</td>
<td></td>
<td>Feelings of mistreatment at school and lack of support during A levels.</td>
</tr>
<tr>
<td></td>
<td>Rebecca</td>
<td></td>
<td>A sense of injustice due to late identification despite her parents frequently expressing concern with her school.</td>
</tr>
</tbody>
</table>

| Heterogenist | Alison     | Strong visual memory skills that helped her cope with her mathematical difficulties. |
|             | Bradley    | Strong visual and artistic skills that helped him cope with mathematical difficulties. |
|             | Ellen      | Some abilities to cope with mathematical concepts when presented in a physical tangible form. |

| Vocationalist | Deborah    | Life in healthcare sector described in great detail. |
|              | Gemma      | Narrative focussed on being a student and her course in Artificial Intelligence. |
|              | Julie      | Had become a lawyer and only had difficulty when she had to pass an accountancy exam. |

Table 17 – Participant alignment to dyscalculia categories

I have assigned participants to the category that they appear most aligned with, based upon the limited data of one interview and grounded theory analysis (see section 6.2). A summary of the participant alignment to categorisations can be found in table 17.

The number of participants in this study who aligned most strongly with Pollak’s category of student was much smaller than in his model. I suggest that this may be because dyscalculia affects everyday life issues more significantly than dyslexia. In the Pollak (2002) study, the vast majority of the dyslexic students’ narratives centred around
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educational issues, whereas the dyscalculic students in my study focussed just as much on problems within everyday life.

11.2.7 Transition between categories in the Adapted Pollak model

Pollak’s (2002) model described how dyslexic students were able to change categories as they became more aware of their neurodiversity and developed coping skills to manage their difficulties. For dyslexic students, Pollak argued that *patient* was the most likely starting category and that a progression to other categories would then take place as the student learned to live with and understand their SpLD. The initial *patient* category for dyslexic students was mostly associated with a pre-identification awareness of having a poor memory, which was perceived as a ‘medical problem’.

In my study, the most common initial category was that of *syndromist*, with only two participants having a starting type of *patient*. I have represented this with a dotted line in figure 25. The possibility of transition by dyscalculic students from the category of *syndromist* to that of *patient*, due to stigmatisation, is represented by an arrow. Most of the dyscalculic students described being *syndromist* during their earlier education, prior to the identification of dyscalculia, as exemplified by Maggie:

> It was really frustrating, because I struggle with the numbers anyway, and then they [teachers] were telling me to do things with the letters as well, and that’s just silly… Sometimes I got to the point where I couldn’t talk to the teacher, because if I talked to the teacher I would just cry because I was so frustrated. (Maggie)

Identification of dyscalculia appeared to be a catalyst for transition between categories for a number of participants. All participants described relief at having an explanation for their previous mathematical difficulties (see section 8.5.4) and this was generally observed as a transition from medical model to social model categories. Transitions that were described in my research data were *syndromist* to *heterogenist* (Alison, Bradley) and *syndromist* to *campaigner* (Fiona, Olivia).

11.3 Social factors informing categorisation

This section lists and discusses the social-based factors that determined the participants’ alignments to certain dyscalculic categories.

11.3.1 Peer comparison as a social factor

One of the most frequently occurring themes affecting participants’ dyscalculic *vocationalist* categorisation was peer comparison. Every participant recounted a number
of stories where they had compared themselves to other students, friends or siblings. They were confused that intellectual equals (or those appearing less able than themselves) had consistently outperformed them in mathematics, as typified by Gemma:

This is going to sound really elitist, but people who are not as intelligent as me on the course overall across the board were doing better in the maths module. (Gemma)

Many participants, prior to identification, and sometimes post identification, struggled to understand and come to terms with this anomaly. Some participants described resentment at having to work harder than their peers. This is illustrated by Heather:

I’d have been embarrassed that everyone else could do it and I couldn’t. I think you don’t understand when you’re younger why you can’t do it. You just think, “Oh I’m just thick and they are so much better than me.” (Heather)

This phenomenon has been described in dyslexic students (Pollak, 2005), and it was Alison with a co-occurrence of dyslexia who was most affected by peer comparison. When the participants observed their peers functioning at a higher level in mathematics, they were experiencing the intelligence disparity effect described within most definitions of dyscalculia (see section 3.3.1.4).

Peer comparison, as a social factor, was a contributor to a number of categories, as it could have either a positive or negative effect. For some participants, it was a source of not only embarrassment, but self-doubt, leading to a negative affirmation of their perspectives as a social individual. Feelings of embarrassment due to peer comparison were often encountered from an early age, as described by Linda.

One person would get up and say one number [in a times tables], and then they would move to the back. And then the next person at the front would say one number and go to the back... if you got anything wrong you would stay in the line. So, I would be in the line forever. I would forever be in the line. (Linda)

For others, rather than being discouraged by peer comparison, they were driven to achieve greater performance, as typified by Bradley:

I thought I was just thick so I really tried to push myself and learn. (Bradley)

Although this was not described as a pleasant experience by Bradley, his use of peer comparison can be seen to have had positive effects, as it motivated him to put in the extra effort required to fulfil his own academic goals.
**11.3.2 Contact with mathematics as a social factor**

Dyscalculia is a neurodiversity that affects the ability to perform mathematical tasks, therefore it is unsurprising that the participants’ experiences of mathematics appeared to have a profound effect on their perspectives as social individuals. Mathematics can be considered a social factor because the desired level of mathematical achievement has been set by societal expectations of teachers and examinations.

All the participants spoke at great length about their overwhelming negative feelings towards their mathematical difficulties. Many perceived themselves as "bad at maths", and some referred to feelings of being unintelligent when discussing their mathematics difficulties. A strong negative disposition towards mathematics appeared to be a particularly strong factor for participants who had adopted syndromist tendencies. Nancy was typical of the syndromist category when she described how mathematics made her feel:

> [I] just thought I was stupid when it comes to maths. (Nancy)

The expectations of mathematics teachers were also a strong contributor to the participants having a poor disposition towards mathematics. They described many occasions on which teachers had reinforced the participants’ impressions that they were incapable of performing mathematical tasks to the required standard. Here Maggie related how she used to cry after mathematics lessons:

> It [crying] was normally if the teacher had spent a long time with me and was really forcing me to understand something and I was really struggling to understand it. That made it worse. So, a lot of the time I actually preferred it if the teacher wasn't around me. (Maggie)

This combination of the topic of mathematics, poor assessment results and unsuitable teaching had led to feelings of despondency in most participants at some stage. For some participants, mathematics lessons became so traumatic, they avoided them completely, as described by Linda.

> I hated them [mathematics lessons]. And I think it got to a point in my later secondary school years where I just wouldn't go. I just stopped going. (Linda)

**11.3.3 Mathematical anxiety as a social factor**

Mathematical anxiety (see section 4.4.1), can also be considered as a factor affecting categorisation. In addition to simple frustration at being ‘poor at maths’ all participants
described some degree of acute physiological stress-response. The powerful nature of this emotional response was a strong determining factor in my aligning participants to a medical model category, such as patient (see figure 25). The influence of mathematical anxiety on the participants’ lives is discussed more extensively in section 8.4.

11.3.4 Unfairness as a social factor

Many participants perceived a sense of injustice which conforms to the social model of disability. The source of this frustration varied between participants but included the attitude of teachers and lack of support from the education system. Fiona was angry about the lack of support she had received while in HE:

*I’m thinking “Is it worth me turning up?” because I just don’t know if I’m going to cope with it... I’ve had no support yet because they can’t find somebody to support me.* (Fiona)

Fiona was sympathetic to the support staff at her HEI, but felt unfairly treated by ‘the system’ as she was unable to access the support to which she felt entitled. For Olivia, the sense of injustice was directed mainly towards the teachers at her school who she believed had failed to support her with mathematics throughout her A levels:

*I re-took it [the examination] and they told me not to come back the year after, so I didn’t... Though I did get a phone call going, “You passed. Do you want to come back?” I was like, “No, I don’t want to come anywhere near you lot.”* (Olivia)

Rebecca’s anger was aimed less at support, and more at the failure of ‘the system’ to identify her difficulties throughout her childhood:

*I think what also bugged me was the fact that it took so long to get me diagnosed, and I think then it was starting to realise that I was failed so much by the system, and I think that’s what really annoyed me.* (Rebecca)

Identification and support of dyscalculic students is discussed in sections 8.5 and 10.4.

11.3.5 Co-occurrence of neurodiversity as a social factor

Where there was a co-occurrence of more than one neurodiversity, such as dyscalculia with dyslexia, the participant appeared to align to a single category due to consolidation of the characteristics of their neurodiversities. In other words, the multiple labels did not tend to cause alignment to separate categories, but instead provided a single merged neurodiverse profile. This is consistent with research that suggests that a co-occurrence of neurodiversities should not be considered as unrelated ‘labels’, and that arguing that
SpLDs are independent is misleading (Kaplan et al., 2001). As any perspective on a social world concerns the entire person, any categorisation must take place from a holistic perspective, and not just consider learning differences in isolation. For example, when Ellen described taking mathematics examinations, the issues she reported were more likely to be dyslexia-related than due to her dyscalculia:

_I can’t do the maths. I’ve got everything in the wrong order. “That’s why I need extra time in exams. I have to re-read questions 5,000 times. Plus, I forget what exactly the question has asked me. And I’ll focus on one aspect of the whole question, and I’ll forget about the rest of it all. It’s just so annoying._ (Ellen)

Alison was able to adopt a procedural learning style by utilising her strong visual memory skills, a strength of dyslexia, to form the basis of her dyscalculia coping strategies:

_I think that time is the same sort of thing because it’s all very visual... I don’t look at it as numbers either... I know I’ve got two hours. I look at it more like shapes._ (Alison)

Bradley also referred to his dyslexia and visual stress more than his dyscalculia, during his interview. He was comfortable with his coping strategies, which led him to accept jobs as an intern in London, travel to the Czech Republic on a ‘year in industry’ scheme, and decline one-to-one mathematics support for his Arts course.

For most participants with a co-occurrence of dyscalculia and dyslexia in my study, the co-occurrence was a positive factor in helping them align to a more positive heterogenist type where some of their neurodiversity-related strengths could compensate for their difficulties in other areas.

**11.3.6 Parents as a social factor**

Most participants reported that their parents or guardians had played a significant role in many aspects of their life, and were a source of valued support. However, parents were also found to be influential in how some participants viewed themselves. For the participants who had a more positive sense of self-worth and had adopted a social model category, proactive parental support was often cited as a factor. Rebecca’s social perspective had been informed by parents who had actively struggled to help their dyscalculic daughter through her education and on to become a qualified nurse:

_“My parents feel I have been let down by the educational system, because I think dyscalculia was mentioned in 1970-odd. And my mum was like, “Surely to goodness...”_
they should have had alarm bells ringing and you should have been assessed.

(Rebecca)

Rebecca’s story of dyscalculia was not just a personal one, but included her parents’ battles against the educational system to recognise and support her mathematical difficulties. Their views were therefore highly influential in the development of Rebecca’s social awareness.

Although parental support was a factor in most participants’ alignment to a particular social model categorisation of dyscalculia, the vocationalists appeared to be most strongly influenced by parents in their pursuit of HE education or a specific career. Julie was typical, in that her father was a strong role model for her desire to go into HE:

He was an engineer and he designed and invented all sorts of machinery for industry. And so he was really good at it and I just felt I was letting him down. It didn't matter for me, but it mattered for Dad... He never intimated that it was a problem, but I just thought... I knew that he would like his child to be able to do what he could do. (Julie)

The participants in the HAcc group appear more likely to have been strongly influenced by parents to strive for an academic career that may be particularly challenging, given their neurodiversity.

11.3.7 Stigmatisation as a social factor

As discussed in section 11.2.7, stigmatisation can be a factor leading to a participant adopting a patient perspective and also in the decision to disclose. Stigmatisation not only caused embarrassment about the participants’ mathematical difficulties, but led to feelings of disability and inferiority. For example, although I would consider Maggie a syndromist at the time of the interview, she described earlier experiences where she had adopted more of a patient category. Maggie was so embarrassed that she was reticent about revealing her dyscalculia even to her family:

I didn't tell my family. Not at first. I was a bit scared, because I wasn't sure if they had heard of it [dyscalculia]. But when I did tell my dad, he just said, "It makes sense. It's fine." And I relaxed a bit, and since then I've been fine with it. I don't tell randomers [sic]. I don't just go around telling everyone. (Maggie)

Because of fear of stigmatisation, Maggie was secretive about her dyscalculia, and would insist that one-to-one support sessions took place in a private location where she could not be seen by others. She had always hidden her mathematics written work away from teachers and peers wherever possible. This is further evidence that dyscalculic HE students can move between categories as discussed in section 11.2.7.
11.3.8 Disclosure as a social factor

Disclosure of dyscalculia was a factor that helped participants adopt a social model category. As a mature student, Fiona found that she was no longer ashamed of her dyscalculia, and was able to ask for help and openly admit to being unable to perform mathematical tasks:

*I see no reason to kind of hide behind it [dyscalculia] or not be upfront about it and be ashamed of it, because I can’t help it... And I don’t mind, I think, as an adult, now, I don’t mind failing. I think, when I was younger, certainly as a teenager, young adult, you do mind failure because it becomes a bit of stigma then, but certainly since the first sort of round of diagnosis, I’m kind of like “Hey. That’s fine. I can fail now.”* (Fiona)

Fiona’s honesty helped formulate her own image as a campaigner. Having openly talked about her difficulties she was able to relate to her own personal experiences when fighting her case for the support to which she felt entitled. She was also able to talk openly about her mathematical difficulties with others.

The scope and timing of disclosure of dyscalculia appeared to be related to participants’ individual views of the social world. The dyscalculic students in the study chose to disclose their neurodiversity at different times and to different audiences; whilst some participants were open about their dyscalculia, others chose to only reveal their neurodiversity to close family and friends. Generally the older participants had already fully disclosed by the time of entering HE, whilst the other participants were still in the process of choosing when and how information about their neurodiversity should be made public. Fear of stigmatisation however can prevent disclosure, as described by participants with fitness to practise issues (see chapter 12) who were generally more reserved about revealing their identification. Non-disclosure is not necessarily a barrier to reaching a positive social identity. Deborah, for example, was a high achiever (HAch) even though she was guarded about who should know about her dyscalculia due to the fitness to practise issues around working as a health practitioner.

11.3.9 Identification of dyscalculia as a social factor

As described in 11.2.7 identification was a trigger for participants to potentially change characteristics which would result in a transition between categories of dyscalculic HE student. Identification did not specifically dictate the new adopted category, and it could be either from a social or medical model theoretical perspective. In my study however, a social model category was the more likely result of identification of dyscalculia which is
discussed in detail in section 2.3.2. A summary of all the recognised social factors can be found in table 18.

<table>
<thead>
<tr>
<th>Main social factor</th>
<th>Adapted Pollak model category</th>
<th>Theoretical perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical anxiety</td>
<td>Patient</td>
<td>Medical model</td>
</tr>
<tr>
<td>Stigmatisation</td>
<td></td>
<td></td>
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<tr>
<td>Contact with mathematics</td>
<td>Syndromist</td>
<td></td>
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<tr>
<td>Unfairness</td>
<td>Campaigner</td>
<td>Social model</td>
</tr>
<tr>
<td>Co-occurrence of neurodiversity</td>
<td>Heterogenist</td>
<td></td>
</tr>
<tr>
<td>Parents</td>
<td>Vocationalist and other social model categories</td>
<td></td>
</tr>
<tr>
<td>Peer comparison</td>
<td>Can cause alignment to a number of categories both social and medical model</td>
<td>Medical or social</td>
</tr>
<tr>
<td>Disclosure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyscalculia identification</td>
<td></td>
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</tr>
</tbody>
</table>

*Table 18 – Social factors informing dyscalculic categorisation*

### 11.4 Comparison between Grounded and Adapted Pollak models

This section explores the relationship between my newly created categorisation of dyscalculic HE student (Grounded model) described in section 7.6, and my adaptation of Pollak’s (2002) dyslexic student categorisation model described in the previous section. As movement between categories is an important feature of the Pollak model, for a mapping between models to exist, transition between categories in the Grounded model would also need to be a possibility.

#### 11.4.1 Mapping between the two models

By using the Adapted Pollak model and the Grounded model that emerged from my data using a grounded theory perspective, I have already established two possible methods of categorising dyscalculic HE students. These models were created independently of each other but when compared in terms of both participants and social factors (see previous section) they appear to have a strong correlation, as shown in table 19.
Table 19 – Correlation between the two models

This table shows how the two categorisations map one-to-one, as demonstrated by the common participants. This does not mean the models are necessarily identical, as the categories explore slightly different perspectives around similar themes. With more participants the two models may diverge. Perhaps the most predictable mapping was the heterogenist type to the co-occurrence of dyscalculia and dyslexia (CDD) group. This is because co-occurrence of neurodiversities such as dyslexia was found to be a strong factor in both heterogenists and the corresponding Grounded model category. One possible difference, however, was that the heterogenist type could also include non-dyslexics, as both Olivia and Nancy showed some attributes that were consistent with this category. My CDD group however was defined to include only dyscalculic students who were also dyslexic. Three participants, Alison, Bradley and Ellen, appeared in both models.

The next most likely mapping in my expectation was syndromist with dyscalculia with numerosities issues (DWN). The participants with the most fundamental mathematical difficulties were aligned to the category that most reflected their struggles. As a
syndromist associates with a set of weaknesses, this mapping appeared immediately logical as a fundamental difficulty with mathematics was the intrinsic cause of these alignments in both models. There were three participants who shared both categorisations: Linda, Maggie and Nancy.

It also seemed logical that the vocationalist type would relate to the high achievers (H Ach) group. The high achievers in my sample had all been highly career-influenced with the choice of degree focussed on specific professions. Three of the participants matched both classifications: Deborah, Gemma and Julie.

The remaining two mappings were less obvious. The patient group appeared to be mapped to the highly anxious (H Anx) group, as both Quentin and Heather were the only participants associated with both groups. As discussed in section 11.2.1, patient was a less common category within my sample. However, there are potential commonalities between patient and H Anx. Whilst all participants described some degree of mathematical anxiety, those in the highly anxious group reported a very significant level of distress, with one participant experiencing mental health difficulties. If severe mathematical anxiety is considered by the participants from the perspective of a clinical symptom, the mathematical anxiety in itself may become the cause of an individual’s development of the category of patient.

The final pairing was the most complicated, although there was an association of two participants with both models. Initially, there does not appear to be a clear relationship between the campaigner type and the dyscalculic profile of dyscalculia without numerosity issues (DWO). Participants in this group had significant issues with mathematics, but did not describe the same fundamental difficulties as participants in the D W N group, who experienced very severe difficulties which they usually spoke about as insurmountable, and felt unable to overcome. On the other hand participants in the DWO group were generally able to envisage a route to success, although their difficulties were still severe. Although hopeful that they would eventually overcome their difficulties, they often described being less able than participants who were moderately dyscalculic (M D Y) to create their own coping strategies from internal strengths, and as such were the most reliant upon external support to succeed. As the participants reported a general lack of suitable support (see section 10.4.5), they were often left with a sense of resentment and unfairness towards the learning support system. Therefore, participants in the DWO group seemed to have a strong affinity to the campaigner type due to perceived injustice around their lack of support.
Several participants described criteria which matched multiple categories and could have been subjectively aligned with a different category if a subset of their data was used. Therefore although the two models show an exact match of participants, this would not have been a perfect result if several of the borderline participants had been allocated differently. However, all participants described numerous characteristics of the corresponding categories in both models.

The relatively small number of participants in my study compared to Pollak’s would make these findings open to criticism, as the number of participants in each category is only two or three. Further research would need to be undertaken to investigate whether the same categories across both models are valid across a larger sample.

11.4.2 Transition between categories in the Grounded model

The original Pollak model proposed that dyslexic students can move between categories as their sense of self is influenced by society (see section 2.3.3). For example a dyslexic student may consider him or herself a *patient* due to a belief they have a medical condition, but through appropriate one-to-one support his or her attitude to dyslexia could change resulting in the adoption of characteristics that would be more aligned to the *hemispherist* category. These transitions could be sudden as a result of a life changing event such as identification, or could be a gradual change as the student comes to terms with their neurodiversity or develops effective coping strategies. For a mapping between the two models to exist, then some potential for transition between Grounded model categories must also exist.

Whilst transition between categories of dyscalculia is determined by how dyscalculic students view themselves within society, movement between categories would most likely need support, either from an external source (see section 10.4) or internally in the form of enhanced coping strategies. A weakness in this theory could be that some transitions of alignment between dyscalculic categories are less likely.

Table 20 illustrates transitions that were described within the data. Other transitions between categories may also be possible. It shows that transition between categories of dyscalculia in the Grounded model usually require external stimulus. A change to a medical model category may be the result of undertaking a new course that is too mathematically demanding, or the removal of established support mechanisms. Transition to a social model category may occur with the addition of new coping strategies or support, or due to continuing academic success.
Initial category | New category | Cause of change
--- | --- | ---
*Dyscalculic with numerosity issues (DWN)* | *Dyscalculic without numerosity issues (DWO)* | Rebecca’s narrative from her early academic career described a student with severe mathematical difficulties (DWN), but with dedicated support and her own determination, her fundamental issues are now less apparent and she appears more aligned to a less affected category (DWO).

*Dyscalculic without numerosity issues (DWO)* | *Co-occurrence of dyscalculia with dyslexia (CDD)* | From her descriptions of school, Alison would have been categorised as a student with severe mathematical difficulties (DWO). However with appropriate individualised support she was able to create successful coping strategies using her dyslexia-related visual skills. From this she gained confidence in her own ability and talked as much about her strengths as her weaknesses (CDD).

High achievers (HAch) | Deborah described mathematical difficulties during school that would have aligned her to the DWO category. Through her career Deborah was able to achieve great success through a process of selective career decisions and determination to succeed that would now see her categorised as HAch.

Co-occurrence of dyscalculia and dyslexia (CDD) | High achievers (HAch) | As many dyscalculic students in the CDD group already have confidence in their coping strategies, they could go on to achieve success and become more aligned to the HAch group.

Table 20 – Pathways for potential transitions between categories of dyscalculia

It is important to make clear that a transition from one category to another does not suggest that the underlying neurodiversity has been affected. A transition from the DWN or CDD to a more advanced category for example does not indicate that the previous dyscalculic or dyslexic identifications are no longer applicable. What is does suggest is that the individual has developed new coping strategies, or has changed circumstance, so that the neurodiversity is now viewed differently. The allocation of a category refers to
the category that is most aligned to how that individual views themselves socially, and does not preclude that characteristics from other categories are also prevalent. The individual may feel less defined by a label than previously and has learnt to identify more with other aspects of their personality, hence a new categorisation.

11.5 Summary and discussion

As part of the analytical process, it was useful to compare and contrast the narratives of the participants, and cluster together participants where they shared similar insights or described similar behaviour. This resulted in five categories, which can be considered as five differing types of dyscalculic student in HE. A strong caveat must be held over this analysis in that the sample only included 14 participants. Although the findings were valid for the sample under study, a much larger sample would be required to test the suggested models more robustly. The five categories created were dyscalculia with numerosity issues (DWN), dyscalculia without numerosity issues (DWO), highly anxious (HAnx), co-occurrence of dyscalculia with dyslexia (CDD) and high achievers (HAch). Only DWN would be considered dyscalculic under the core-deficit Butterworth model. The participants in the HAnx category were likely to be dyscalculic under this model, but the high levels of general anxiety would make it difficult to isolate their mathematical difficulties from wider issues. In future research it should be possible to map other dyscalculic HE students to this categorisation to test its validity. A robust categorisation could help in differentiating support strategies and in exploring the nature of dyscalculia.

This section also explored the categorisation of dyscalculic students using Pollak’s (2002) model from the discourses of dyslexic learners as a framework. I found all of Pollak’s categories to be represented for dyscalculic students, including that of the syndromist, which in Pollak’s study remained theoretical. The difference in prevalence of patient and syndromist categories between the two studies may be related to perceptions of memory issues in dyslexics who view this as a medical problem, or due to the stigmatisation of neurodiverse individuals in different cultures. I have adapted Pollak’s (2002) model to better reflect the social perspectives of dyscalculic students in the following ways. The category of hemispherist has been renamed to heterogenist to reflect the fact that the strengths and weaknesses of dyscalculia are not related to hemispheres of the brain. The student category has been expanded and renamed vocationalist to include dyscalculic students who align to an identity related to their chosen future career.

The Adapted Pollak model was based upon how the participants viewed themselves, and it was interesting that these ideas regarding identity correlated with their descriptions of academic and everyday events. This emphasises how their socially constructed identities
were intertwined with how they positioned themselves in their respective mathematical communities. From a socio-cultural perspective, learning can be considered as a function of shared social practice. Participants described how society, in the form of peers, teachers, parents and educational targets had conveyed to them an expected level of mathematical achievement. With this came awareness that their level of mathematical understanding was significantly lower than societal expectations. Luria (1990) stated that researchers should think of self-awareness as a product of "sociohistorical development" that begins with a "reflection of external natural and social reality" (p145).

Further research with a larger sample would be needed to show that the Adapted Pollak model is analogous to the Grounded model.

This chapter demonstrated that there is a strong connection between the Adapted Pollak model for dyscalculic HE students, and the Grounded model defined in section 7.6. This correlation has been demonstrated by the accuracy of participant mapping and the social factors linking the two taxonomies. Whilst most of the mappings are obvious, I have offered possible explanations for the links between the more complex connections.

Although the models appear to map to each other across fourteen participants, it is likely that they may diverge over a larger study as the defined categories, although similar, are not identical.

I felt that the connection between DWO category in the Grounded Model and campaigner in the Adapted Pollak model was of particular interest. This implies that dyscalculic students with the most severe fundamental differences are focussed inwards towards their difficulties and less able to look outwardly to society to seek support. The transition between medical and social models of the DWN and DWO categories is crucial as the dyscalculic students can only gain a sense of injustice once they realise that the reason for their difficulties is not medical. Dyscalculic students aligned to the DWN category may have feelings of depression or anger, but they are focussed on what they perceive as bad luck rather than any fault of society, which would be a trait of a social mode category. The social model categories of CDD and HAch had developed their own coping strategies and were more self-sufficient and independent learners. It was only the students in the DWO category who recognised that their learning was a function of participation in society and that they did not have the skills to overcome their difficulties. They recognised, however, that society was at least in part responsible and they therefore were more able to ask for support. They felt that support was their right and were therefore campaigners according to Pollak’s model.

Also of interest is the fact that Pollak felt campaigner was one of the most advanced categories, or identities. The Grounded model suggests otherwise, however, as it is the
first social model identity, and would be placed third of the five categories in order of self-efficacy or agency. The Grounded model perceives CDD and Hach as more advanced categories that participants could progress to as they found working coping strategies and achieved mathematical success.

As the ability to move between categories of dyscalculia is central to the possibility of mapping of the two taxonomies, I have identified examples where my participants described a change of characteristics in the past and explored the catalysts to this change. In line with Pollak's previous work, I have also considered possible 'starting categories' of dyscalculic individuals and how they may transition between these and others, particularly upon identification of their dyscalculia. I was aware that the potential movement between categories in the Grounded model was a weakness of the mapping between models. Whereas identity could change suddenly after a particularly influential experience in the Pollak model, the movement between categories in the Grounded model would be slower as they reported on behaviours, which are more likely to alter gradually.

On reflection, one criticism of the Grounded model could be the restricted scope of the CDD category. By definition this stipulates the presence of the two neurodiversities, but what was described in the Pollak model was the use of strong coping strategies using character attributes not typically associated with mathematics. Participants such as Olivia and Nancy, although not dyslexic, showed some evidence of aligning to this category. A more appropriate definition for this category might include reference to coping strategies rather than dyslexia.

This chapter has also explored the social factors that have influenced the participants to align with particular categories of dyscalculia. It has been shown that there are particular social factors that map to each category (see table 18), as well as other social factors such as peer comparison, disclosure and the identification of dyscalculia that also have a strong influence on dyscalculic HE student categorisation, albeit with less predictable results. Social factors were introduced to help understand the relationship between the Grounded model and the Adapted Pollak model. Where a social factor appeared to support the alignment of a participant to a category in one model, the same effect was seen in the other. Although most of the social factors that informed categorisation aligned a participant to a particular category, scenarios can be imagined where the same social factor could produce a different result. For example, parental influence in my study led to a number of dyscalculic students becoming high achievers (H Ach), but anecdotally I am aware of occasions where parents have been unsupportive, so the relationship between parents and dyscalculic students is far more complex.
12 Fitness to practise

12.1 Introduction

The fitness to practise of neurodiverse employees within the public sector has been the subject of much debate, as discussed in section 5.10. The pilot survey into the incidence of dyscalculia in HE, as described in appendix I, showed that there was a high prevalence of dyscalculic students enrolled in subjects allied to medicine, more than any other subject area as defined by the University and Colleges Admissions Service (UCAS).

There were three students in the sample for whom fitness to practise was an issue: Deborah and Rebecca, who were both healthcare students, and Heather who was studying to become an early years’ teacher. This section explores fitness to practise in the context of healthcare and education through the experiences of the three participants in these sectors. The methods used to test these proficiencies are outlined, and the students’ perceptions and experiences in the workplace explored. As I chose to include the mathematical experiences of dyscalculic students in a single chapter, a discussion of the mathematical proficiency required for specific job roles is discussed in section 9.5.4.

It should be reinforced that this section is unlike others in the thesis, as there were only three students for whom these issues were relevant and these limitations must be considered when interpreting the findings. However, despite the limited number of dyscalculic students involved, existing literature on dyslexia (Sanderson-Mann & McCandless, 2006) and mathematical anxiety (Glaister, 2007) suggests that the effect of mathematical difficulties on healthcare practice is a topic of great importance and I have therefore chosen to include this section. It was the most prevalent theme arising from the narratives of the participants who were affected by fitness to practise issues.

12.2 Defining competence

The fundamental question surrounding fitness to practise is whether the dyscalculic practitioner is capable of performing the duties required by their role. Some professional competencies utilise skills that are inherently mathematical in nature, though some participants in my study felt that the emphasis on the mathematical elements was out of proportion with other aspects of their professional role:

*I understand you have to have some like, degree of maths, you have to know what you’re doing, but I think they should more concentrate on your lesson plans and different lessons for children, not if you can do your times table.* (Heather)
Heather was frustrated at what she perceived as the unfairness of the qualified teacher status (QTS) tests that are used to determine mathematics competence for teachers, and that they did not take into account her neurodiversity or her broader skills as a teacher.

As a consequence of a focus on the mathematical components of their role, all three participants had become resentful that their weaknesses were being highlighted to the detriment of their strengths, as exemplified by Rebecca:

*I think what really pissed me off as well was the fact that I could understand if there were aspects of the course that I was struggling with as well as the numerical, but I passed everything [else]. I think it’s unfair to say, ”I’m sorry, but you can’t look after people.” There’s more to nursing than number work. Yes, it’s a big part of it. I’m not disputing that.* (Rebecca)

Rebecca reported that when she was initially identified with dyscalculia, the HEI had suggested that she would be unlikely to become a nurse due to her neurodiversity:

*To be taken out of uni and to be told that you’ll probably never nurse and never get a chance to go back … It was incredibly depressing, because that’s all I had really wanted to do and it was something that I was good at.* (Rebecca)

Rebecca’s perception that she had been denied a future in a career she felt passionate about made the decision to leave the course a traumatic event that led to years of emotional distress.

As drug calculations and reading charts are a compulsory element of the job description for nurses and midwives, the mathematical component of the role cannot be delegated to other staff members. The Nursing and Midwifery Council (NMC) fitness to practise standards (2014) attempt to ensure that all practitioners are able to perform the mathematical parts of the role to the required standard on a daily basis by a strict regime of assessment during qualification and regular drug calculation testing whilst in post. The two healthcare practitioners in my study had demonstrated that despite dyscalculia it was possible for them to achieve these performance thresholds and reach the required standards for registration with the Nursing and Midwifery Council (NMC). Furthermore, although both healthcare participants described mathematical difficulties in the clinical setting, there was no suggestion from their narratives that they felt they could not do their job or had ever knowingly put a patient at risk. Neither related an incident where a clinical error had taken place. Deborah had already had a successful career as both a nurse and midwife, and Rebecca, having had her difficulties initially identified by her employers, had been assessed as safe to practise:
Chapter 12 – Fitness to practise

All my placements were fine. There was no issue at all. And in fact, on my last placement in surgical, they said, "We've got no concerns about your numerical issues. You're perfectly fine doing a drug round." (Rebecca)

Rebecca had undertaken a number of lengthy clinical placements where her practice was supervised and observed. Despite her mathematical difficulties, which she had disclosed, she was able to demonstrate that her practice was safe due to successful implementation of her own individualised coping strategies. These success stories show that it is possible for a dyscalculic student to become a nurse despite their neurodiversity. Although an Educational Psychologist’s assessment of neurodiversity describes both the strengths and weaknesses of the student, the resultant label of dyscalculia may be interpreted by some as only representing the potential level of difficulty faced by the student, not their strengths and abilities to overcome those difficulties. Rebecca cited hard work, extensive practising of worked examples, revising from notes, openness to her difficulties and dedicated one-to-one support during HE as factors contributing to her success.

12.3 Safety and hyper-vigilance

Section 4.8 discusses the existing regulations around mathematical competence of drug calculations to ensure patient safety, and debates around the practice of neurodiverse healthcare practitioners. The potential for concern about the ability of the participants to practise safely does not rest solely with HE supervision or hospital management. The healthcare students in the study both described incidents where colleagues had expressed an opinion that dyscalculia is incompatible with fitness to practise in the healthcare sector.

I’ve had people say to me that I shouldn’t be a nurse, that I’m a danger, that I’m a risk to people... I’ve had nurses put it to me in simple... You know, they’ve worded it in a way, but that’s what they’ve meant. I shouldn’t be on the wards... that I’ll be a danger. (Rebecca)

This is an example of some members of the chosen community of a dyscalculic student explicitly rejecting their membership. Dyscalculic individuals may already lack confidence in the legitimacy of their membership of a community of practice involving mathematics, and an unsupportive attitude from colleagues may exacerbate this lack of confidence and present further barriers.

The healthcare students in this study were acutely aware of the risks of prescribing and administering drugs, and of their responsibilities within these activities, and felt that the unsupportive attitude from some peers was unfair:
I know I need to be safe. (Deborah)

Both healthcare students in my study described using extra diligence to ensure that drug calculations had been performed accurately:

If I’m counting say, things like Prednisolone is five milligram tablets and I’ve got to give thirty milligrams I count it really carefully, and I find myself rechecking to make sure that I’ve got the right amount. (Deborah)

Although this hyper-vigilance (see section 5.10) may have implications for efficiency and time management in the clinical environment, it could potentially result in safer practice than that of neurotypical practitioners (Murphy, 2009). When Rebecca began her first clinical placement, she recognised that her practice was not safe and chose to withdraw from the course.

My main priority and concern was the care of my patients. I said, "I’m really sorry, but I can’t deal with this. I’m terrified I’m going to kill someone or harm someone." So, the uni was contacted [by my ward supervisor] and I was taken off the course. (Rebecca)

It was a brave decision to admit her mathematical difficulties and how they were affecting her practice, but showed that her priority was the safety of her patients:

12.4 Mathematics competence tests

Two of the three participants in the fitness to practise group had to take a mathematics test to prove their fitness to practise. For teachers, this is the qualified teacher status (QTS) test taken before teacher training. For healthcare practitioners, numeracy tests with a pass mark of 100% are now taken during training, on appointment to a post and on an annual basis in most substantive posts (see section 5.10).

Both Rebecca and Heather experienced these tests recently as students, but Deborah as an existing practitioner in a previous career had not taken a test. Some practitioners have criticised the test for taking drug calculations out of context, and sometimes creating non-realistic scenarios that have confused practitioners (Wilson, 2003). In nursing and other allied health professional courses, software packages are available to help the students master contextualised mathematics such as drug calculations, as described by Rebecca:

[University name] have an online tool, which, when you’re a student, you’re given access to... Basically with nursing, you’ve got a formula that you go over... So I spent
most of my uni plugging away with this software and working with my maths tutor.

(Rebecca)

The online tool described by Rebecca was available to all students on her course, and licensed by her academic department. Rebecca felt that it was a major factor in her finally passing her numeracy exam after multiple attempts. This software could be beneficial for many dyscalculic students, to help them view mathematics concepts and offer procedural methods of approaching common problems, especially if they were adapted to be relevant to their own course. The software could also provide dyscalculic students with repeatable practice tests and automated verification, although mathematical anxiety is likely to be a factor.

The mathematical element of the QTS test is established as challenging for students of non-mathematical subjects who have had little or no exposure to mathematics for some time (Fletcher & Mooney, 2007). For a dyscalculic student in this situation, the tests form a significant barrier to reaching the goal of becoming a teacher. It is conceivable that Heather and many other prospective dyscalculic teachers may fail the mathematics test and be excluded from teaching. The primary difficulty described by Heather was the amount of time available for each question. The first part of the test consists of a series of mental arithmetic tasks which must each be completed within eighteen seconds, (Department for Education (DfE), 2014) although a longer time can be negotiated for those students qualifying for reasonable adjustments (see section 5.2):

And if I had like an hour to do the whole test I’d be fine, because it is, I get twenty seconds or whatever it is to answer the questions. (Heather)

For a student with poor working memory or slow processing speed, this could be problematic, and for students in the highly anxious (HAnx) group this may be a particularly stressful environment, as illustrated by Heather. By including a mental arithmetic component in the QTS test, the Department of Education has ensured that an ability to perform these types of calculations is a required competence for fitness to practise as a teacher.

12.5 Disclosure and confidentiality

Macdonald (2010) claimed that a label of dyslexia can be not only stigmatising but potentially harmful to an individual’s career prospects. Disclosure was therefore a particularly important theme for participants studying for careers with formalised fitness to practise requirements. The Disability Rights Commission stated that "there are a range of concerns expressed by disabled people around the real and perceived
discriminations against them as a result of disclosure. The implications of nondisclosure, however, are that support may not be rendered or that discrimination cannot be tackled effectively. Interventions may therefore not be timely” (Dale, 2007, p29). Under the terms of the Data Protection Act (Parliament, 1998), a dyslexic health practitioner has the right to conceal their neurodiversity from their employers as part of their own personal sensitive information.

In this study, Deborah, an existing practitioner, was the least inclined to disclose her neurodiversity. This was illustrated by her concern that the provision of extra time in examinations would highlight her learning difference to her peers:

> Well, more often than not, we're in a separate room. This situational judgement test this morning, we were at the front. So you're always identified. (Deborah)

Riddick (2000) argued that students with a visible disability, such as wheelchair users, and students with a hidden SpLD, can display different attitudes towards their disability. Unlike the first group, students with a hidden SpLD can choose when to disclose their difficulties, and this sense of agency can be important to their identity. The impact of disclosure on the dyscalculic students’ identity is explored further in section 11.3.8.

### 12.6 Role specialisation as an avoidance strategy

The avoidance of degree courses with mathematical content has already been established in section 8.3 as a strategy for making career choices. Within professions with fitness to practise legislation, the participants used similar strategies to pilot a career path which would limit their exposure to mathematics. For example, roles within the healthcare sector involve differing levels of mathematical content and the participants were able to take control of their career path to lessen the effect of their dyscalculia, as described by Deborah:

> If anybody ever asked me "Why didn't you go into paediatrics?" That was my answer. And that still is my answer, the calculations. (Deborah)

Deborah was aware that the requirement for mathematical proficiency would vary between specialities and had chosen a career path to limit her exposure. Student teacher Heather had made similar choices. She opted to teach early years’ primary children where she felt that the level of mathematics would be within her conceptual understanding:
Chapter 12 – Fitness to practise

I think that’s another reason why I’m doing early years... My nephew’s in year six, and he asked me to help him with his homework and I couldn’t. So I’m never going to apply for a job if they’re older than say year three. (Heather)

For healthcare practitioners, it was not just mathematics that determined the practice choices, but also the level of risk involved. Deborah described a preference to move into pathology where the risks to lives would be minimised, as she was well aware of her duty to practise safely. This does not mean that she felt that she was unsafe in other areas, rather, that the role would be less stressful and require less time consuming coping strategies. She went on to say:

There’s some things that I know I definitely won’t go into, like, A and E. (Deborah)

This was because she was aware of the time-critical nature of emergency care and felt that the impact of time pressure would negate her coping strategies for her dyscalculia.

12.7 Summary and discussion

This chapter explored issues specific to three dyscalculic students entering careers with formalised fitness to practise regulation, which in this study were healthcare and teaching. The strength of the data accompanied with anecdotal evidence and recent literature suggests that fitness to practise could be the most politically important aspect of dyscalculia in the HE domain. The fundamental question being asked in these sources is whether a dyscalculic practitioner can meet the requirement standards to practise safely and competently with their mathematical difficulties (Cowen, 2015). The themes emerging were the definition of competence, safety and protection of the public, testing for competence, issues around disclosure and role specialisation.

As my research has shown, there are different categories of dyscalculic student and each has varying strengths and weaknesses. Both Deborah and Rebecca have found success and proved their capabilities despite adversity. The practitioner, within the social model of disability, should only be judged on their ability to perform the mathematical tasks required in their practice, and not simply on their ‘label’. The participants in my study gave examples of being pre-judged by their peers, and anecdotally I have heard opinions from hospital managerial staff that dyscalculic healthcare practitioners with responsibility for drug calculations are incapable of safe practice, despite the Equality Act (Parliament, 2010). It is understandable therefore, that some dyscalculic students may choose not to disclose their neurodiversity to avoid the scrutiny of their practice which may follow. The counter argument to this is that with disclosure, the dyscalculic student could become
entitled to reasonable adjustments, which may make the difference between failing to acquire the mathematical competence standards and successful safe practice.

The dyscalculic healthcare students in this study displayed the same hyper-vigilance as observed in dyslexic practitioners in previous research, and appeared to be aware of their limitations and duty of care. Both healthcare participants had reached the required standards for professional registration, suggesting dyscalculic students should be judged upon individual merits and not by an identification label.

Heather, the only teacher in my sample, struggled to pass her qualified teacher status (QTS) tests because of her mathematical difficulties and resented the fact that she was expected to understand a level of mathematics beyond that which she would be teaching to her early years students. Due to her dyscalculia she described a procedural learning style based upon a view that the nature of mathematics is a set of unconnected procedures. As Heather does not have a conceptual understanding of many mathematical topics, it would be difficult for her to teach mathematics to students who would prefer a more conceptual understanding based approach to acquisition of knowledge.

Deborah, Rebecca and Heather are studying subjects linked to professions where they have to demonstrate overtly a capability to perform mathematics. In both their nursing and primary school teaching careers, they have been tested to ensure they reach a minimum numeracy requirement. Fitness to practise issues had accentuated the difficulties faced by Rebecca and Heather, creating significant stress and anxiety. Sabin (2001) described the importance of creating a suitable learning environment for healthcare practitioners that would be relevant for all fitness to practise sectors. He claimed that if health sector “education views mathematics as non-contextual, then we risk losing the potentially rich sources of learning available from the use of real life scenarios” (p8). But Sabin goes on to warn however that “if we view all calculation as contextually bound, then we risk adopting a ‘cookbook’ strategy of protocols and prescribed formulae with a resulting failure to support problem solving and critical thinking” (p8). The “contextually bound” “cookbook” method that he refers to corresponds to the preferred learning style of dyscalculic learners as discussed in section 10.2.1, which suggests that dyscalculic health practitioners could perform well when adopting one style of learning, but struggle with other methods.

This study was unable to provide much reliable insight into fitness to practise issues due to the number of participants studying relevant subjects. Further targeted research with
a suitable sample is imperative to better understand the issues of a dyscalculic practitioner in a field with formalised fitness to practise requirements.
13 Conclusion

The final chapter summarises the results of this research, makes recommendations and suggests potential areas for further study.

13.1 Concluding summary

This research has contributed to the existing knowledge of dyscalculia in a number of ways. It provides insight into current identification processes, and students’ reactions to those processes. The study examined the mathematics that dyscalculic students find particularly difficult in HE and highlighted two areas of conceptualisation difficulty that are under researched. The thesis explores how dyscalculic students learn mathematics and which reasonable adjustments can be effective. Finally, the study examined the question of whether dyscalculic HE students have similar academic profiles.

The study showed that dyscalculic students can be categorised into five different groups. The students in these categories described varying levels of dyscalculic difficulty and had developed differing behaviours and coping strategies. The analysis of the data was performed using a framework using these five dyscalculic student categories and the findings were often related to those categories. I went on to show that the Grounded model of categorisations of dyscalculic HE students had strong parallels with the Pollak model for dyslexia, even considering that Pollak had modelled identity rather than characteristics.

Dyscalculic students had taken a number of routes to enter HE, with most accessing FE without the need for a ‘C’ grade in GCSE mathematics. Their subject choices seemed to follow four trends, which in my sample, were equally prevalent. These trends were based around themes of avoidance, lack of awareness of mathematical content, misplaced trust in coping strategies and choosing a career path that was laden with mathematical difficulty due to being career driven.

Mathematical anxiety (MA) was shown to be a major component of dyscalculic students’ experiences with all participants describing the presence of MA at various points through their education and everyday life. Specifically, the participants described experiencing a mental block, which is the inhibition of working memory, an established feature of MA. Participants who had received good one-to-one mathematics support appeared to be less susceptible to experiencing MA.

The participants were overwhelmingly positive about identification, as it allowed them to finally understand the reasons for their difficulty. Some participants also had negative
feelings of resentment about the length of time taken to reach identification and some also expressed concerns about stigmatisation. Two participants also suggested that they were less inclined to attempt mathematics once they knew they were dyscalculic, whereas previously they had achieved mathematical success through hard work and perseverance.

Chapter nine addressed specific mathematics topics that dyscalculic students find difficult in HE. The participants described many instances of arithmetic issues involving integers, non-integers and number facts. Only the most severely dyscalculic students showed evidence of the fundamental difficulties with number sense described by Butterworth’s core deficit module. There were also two conceptual difficulties described by the most severely dyscalculic students which have so far have received little discussion with respect to dyscalculia: comprehension of non-integers and non-cardinality. Comprehension of non-integers concerns the ability of a severely dyscalculic student to conceive of the existence of a number that is not whole. Non-cardinality refers to the use of numbers outside numerosity, where objects are assigned a numerical value based on non-physical attributes. Time was also reported as an area of major difficulty, with dyscalculic students struggling with telling the time, calculating time and judging the passage of time.

With regard to the applications of mathematics that cause problems in HE, statistics was the topic most commonly raised. Simple graphs such as bar charts presented few difficulties, but any graph that required the student to read an axis was problematic. Graphs with more than one-dimension, such as x-y plots, were also described as difficult as the participants experienced problems in understanding how the two axes related to each other. A third issue known as iconicity also emerged, and describes how a graph may remove the viewer from the relevant context. Difficulty with standardised units and money were also described. The mathematics involved with courses associated with fitness to practise legislation was a major concern to the three participants for whom this was relevant. So called 'fitness to practise' careers include healthcare and teaching. Although I did not have enough participants to study fitness to practise in any great depth, it is clearly a major area of concern in the field of dyscalculia.

With respect to learning, this study described a number of learning methods preferred by dyscalculic students. These concerned learning style, media and environment. There was not a consistent preferred learning method for all participants, with this being shown to relate to their dyscalculia profile. However, all the participants described a strong preference for procedural learning, and struggled with understanding mathematical concepts. One-to-one support was described as by far the most effective reasonable
adjustment, with all participants who had been offered this support speaking positively of the benefits. Availability of a suitable tutor was shown to be an issue for many participants. Other reasonable adjustments that could be beneficial were identified as mathematical software, audio recorders for note-taking and extra time in examinations.

13.2 Implications and recommendations

There are a number of recommendations from this study that could be implemented into existing practice. These cover areas of career advice, identification, needs assessment and support.

The study has shown that some dyscalculic students are unaware of the mathematical content of the subjects they choose to study in HE, and cannot therefore make an informed decision regarding the mathematical challenges they may face. This could be improved through more detailed information on HEI websites, or better training for practitioners involved in offering career advice.

Identification of dyscalculia, with a few exceptions, was seen as positive. However, identification often took place whilst the students were in FE or HE. More needs to be done in primary and secondary schools to raise awareness and provide opportunities for earlier identification. PGCE training for mathematics teachers should include teaching sessions on mathematical difficulties caused by dyscalculia and other neurodiversities, so they may recognise potential SpLDs at an early stage.

This study has shown that one-to-one support is likely to be the most effective reasonable adjustment for supporting dyscalculic students in HE. This support needs to be tailored to the specific needs of each student, which will be guided by the student’s categorisation of dyscalculia. Learning support tutors need to consider the preferred learning style, media and environment of the student. Tutors should try to match the nature of the support to the learning needs of each student. Before effective support is possible, the emotional well-being of the student needs to be considered. This may include provision of practical help with everyday life issues caused by mathematics difficulties, or the stress-related problems caused by mathematical anxiety or general anxiety in the case of the highly anxious (HAnx) category. It is likely that all dyscalculic students are at risk of some degree of mathematical anxiety and strategies to reduce this are imperative to success.

The lack of available one-to-one support was another major issue highlighted by the study. Provision must be made for all dyscalculic HE students to have this type of
support made available, and tutors must be trained in both the mathematical needs of the student in HE and the issues created by dyscalculia (or other neurodiversities).

Other recommendations around reasonable adjustments are the consideration of mathematical software and audio recorders for note-taking. Typical dyslexia-related adjustments such as laptop computers or library privileges do not appear to be effective for dyscalculic-only students. Calculators should be allowed in all examinations.

13.3 Recommendations for secondary teaching

Although the domain of this research has been HE, it is possible to consider how the findings could impact upon secondary mathematics teaching. Some of the recommendations such as one-to-one support or in-situ contextualisation may not be possible in a classroom environment, but other findings could be applicable.

The first consideration would be the ability of secondary mathematics teachers to recognise dyscalculia characteristics in a student and recommend identification, if such a process exists. Data in this study has shown the importance of identification for the participants to restore self-esteem that there is an explanation for their mathematical difficulties and that they are not “stupid”. Many expressed regret that hey had not been identified earlier while at school. Even if a school is unable to provide an official identification, a teacher could use the knowledge of dyscalculic tendencies to provide support strategies for the student, and encouragement that their difficulties may have a cause that does not reflect on their general intelligence and their potential to achieve academic success.

Once a teacher has recognised a possibly dyscalculic student, then there are strategies that could be employed given a large classroom situation. The reduction of mathematics anxiety would be important, so the creation of a supportive positive learning environment would be a key. Although in-situ contextualisation would not be possible, the use of contextually relevant manipulatives could be beneficial, i.e. everyday life objects as opposed to abstract shapes and blocks. The use of more verbal descriptions rather than just numerals and symbols could also benefit a dyscalculic learner, and other neurotypical learners with differing learning needs.

Knowledge of a dyscalculic student’s potential preference for procedural learning could also be beneficial to a secondary mathematics teacher. Although conceptual learning should still be the focus, teachers may have to accept that procedural practices may yield better short term results, and some positive results may contribute to greater mathematical confidence.
Although a teacher would not have the time to work one-to-one with a student, they may be able to recognise the strengths of a student and encourage the student to create compensating coping strategies. Any individualised support and encouragement is likely to be constructive and help with the student’s self-esteem.

13.4 Personal reflection

Although I am an experienced mathematics teacher, my knowledge of dyscalculia, especially within an HE setting, was limited when I began this study. Due to my chosen grounded theory approach, I now feel that I have not only a better understanding of the nature of dyscalculia, but also of what the students feel are the important issues to them. Although the target population was relatively small, which would have presented a risk to the success of the project, I have been lucky in that the participants when approached were overwhelmingly positive and gracious about talking about their experiences. For many this was the first opportunity they have had to describe their lives and the challenges they have faced. What I had initially expected to be an hour interview, often lasted twice as long.

It has been a challenge, during analysis, to keep focus on the student voice, especially when comparative literature in the field is often concentrated around the neurological reasons for dyscalculia. Where I have excluded medically-based literature on dyscalculia, it is not that I view this research as less important, but rather that it does not answer my research questions which seek to focus on the student experience. Where I have included references to literature based in neuroscience, it was a challenge to represent that work faithfully but avoid the medical model language that is in conflict with my own theoretical perspective. I could have chosen to exclude literature from such a diverse theoretical background, but as it was the only existing literature in many cases, I felt it should be included to provide context for this study.

A challenge throughout this study has been that of scope. The grounded theory approach revealed some diverse themes which required varying directions of background exploration. If I had chosen a more focussed set of research questions, then the study would have been more manageable, but restricting the scope was difficult due to the wealth and depth of data I collected. I had to exclude from this thesis some powerful recollections of childhood experiences that highlighted the poor experiences of dyscalculic children, which I felt was a missed opportunity to understand the experience of dyscalculic individuals and hope that this can be explored in further research.

Another challenge was the amount of mathematical content within the study. As I suspected most participants would struggle with mathematical anxiety, I was wary of
posing mathematics questions during the interview. I had therefore assumed that little could be learned about the actual mathematical difficulties and my initial focus was more upon the students’ experiences of learning and support. As my PhD has been supported by a mathematics education department, I was concerned whether the lack of theoretical mathematics was an issue. However once a separate chapter had been created to contain all the mathematical findings, it became clear that the level of mathematical content was substantial, and I feel that an appropriate balance was achieved.

13.5 Future research

As the scope of this research was broad, several areas of interest were raised that could not be explored in depth due to the limitations of the study. The following topics are areas I feel would benefit from future research in order to gain a deeper understanding of the needs of dyscalculic students.

13.5.1 Mathematical anxiety and dyscalculia support

This study has shown that one-to-one support can alleviate mathematical anxiety (MA) and ‘free-up’ working memory, which is required for many dyscalculic students preferred procedural learning style. Further study could investigate strategies to help dyscalculic learners overcome MA and gauge the effect this has on mathematical performance.

13.5.2 Comprehension of non-integers

The study provided some evidence that severely dyscalculic students may struggle with the conception of non-integers. A study that focusses on non-integer properties rather than representative formats may provide further insight into this subject.

13.5.3 Non-cardinality

Previous dyscalculia research has concentrated on numerosity, and little is known about how dyscalculic individuals interpret non-cardinal numbers. A study exploring this concept in depth could reveal more about the nature of dyscalculia and show that the amount of focus on numerosity issues as a characteristic may be disproportionate.
13.5.4 Iconicity and in-situ contextualisation

The need to perform mathematics within a relevant context and subsequent difficulties with mathematical abstraction were strong themes to emerge from the study. Future research could explore support interventions that make use of this knowledge to help dyscalculic students gain a better understanding of mathematical concepts.

13.5.5 Time perception

Difficulty in perceiving the passage of time was a theme discussed by several participants, and anecdotally is also a characteristic of other SpLDs. I am unaware of any research that has explored this concept. The creation of a study methodology would however be difficult as participants would need to be monitored over a period of hours.

13.5.6 Fitness to practise

The study was unable to explore the area of fitness to practise in any depth due to the lack of relevant participants. A research study in co-ordination with an HEI with a large population of healthcare students could explore more of the issues involved and subsequently inform the development of support and policy strategies.
Chapter 14 – Related work

14 Related work

14.1 Publications


14.2 Related conference presentations


14.3 Related academic presentations


Chapter 14 – Related work


15 References


American Psychiatric Association (DSM-II). (1968). *Diagnostic and Statistical Manual of Mental Disorders (DSM-II)* (2nd ed.). Arlington, VA, APA.


References


Choy, S. (2001). *Students whose parents did not go to college: Postsecondary access, persistence, and attainment*. Findings from the National Center of Education Statistics.


References


Department for Education (DfE). (2011). *Teachers’ Standards Guidance for school leaders, school staff and governing bodies*.


References


Lapadat, J. C., & Lindsay, a. C. (1999). Transcription in Research and Practice: From Standardization of Technique to Interpretive Positionings. *Qualitative Inquiry, 5*(1), 64–86.


Trott, C., Drew, S., & Maddocks, H. (2012). A hub service: extending the support provided by one institution to students of other local institutions. *Higher Education Academy.*


### Appendix A – Definitions of dyscalculia

<table>
<thead>
<tr>
<th>No.</th>
<th>Author</th>
<th>Year</th>
<th>Definition</th>
<th>Criteria / Notes</th>
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</table>
| 1   | Kosc    | 1974 | A structural disorder of mathematical ability, which has its origins in a genetic or congenital disorder of those parts of the brain that are the direct anatomico-physiological substrates of the maturation of mathematical abilities adequate to age, without simultaneous disorders of general mental functions (Kosc, 1974, p165). | Arithmetic academic achievement (new)  
Test age appropriateness (new)  
Intelligence disparity (new) |
| 2   | DSM-III | 1980 | 1) Arithmetic skills as measured by a standardised, individually administered test are markedly below the expected level, given the person’s schooling and intellectual capacity (as determined by an individually administered IQ test).  
2) The disturbance in (1) significantly interferes with academic achievement or activities of daily living requiring arithmetic skills.  
3) Not due to a defect in visual or hearing acuity or neurological disorder. (American Psychiatric Association (DSM-III), 1980) | Arithmetic academic achievement,  
Test age appropriateness  
Intelligence disparity  
Educational opportunity (new)  
Educational issues (new)  
Everyday life issues (new)  
Absence of unrelated impairments (new) |
| 3   | ICD-10  | 1992 | 1) This disorder involves a specific impairment in arithmetical skills, which is not solely explicable on the basis of general mental retardation or of grossly inadequate schooling. The deficit concerns mastery of basic computational skills of addition, subtraction, multiplication, and division (rather than of the more abstract mathematical skills involved in algebra, trigonometry, geometry, or calculus).  
2) The child's arithmetical performance should be significantly below the level expected on the basis of his or her age, general intelligence, and school placement, and is best assessed by means of an individually administered, standardized test of arithmetic. Reading and spelling skills should be within the normal range expected for the child’s mental age, preferably as assessed on individually administered, appropriately standardized test.  
3) The difficulties in arithmetic should not be mainly due to grossly inadequate teaching or to the direct effects of defects of visual, hearing, or neurological function, and should not have been acquired as a result of any neurological, | Arithmetic academic achievement  
Intelligence disparity  
Educational opportunity  
Test age appropriateness  
Standard literacy academic achievement (new)  
Absence of unrelated impairments  
Educational issues  
Everyday life issues  
Standard literacy academic achievement criterion does not allow for co-occurrence with dyslexia. |
psychiatric or other disorder. The disorder is distinguished from acquired arithmetical disorder or acalculia (coded as R48.8 in the ICD-10). Latter diagnosis stands for a loss of previously present arithmetical skills as opposed to the failure to acquire them in the former (World Health Organisation (ICD-10), 1992, F81.2).

<p>| | | | |</p>
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<tbody>
<tr>
<td>4</td>
<td>DSM-IV</td>
<td>1994</td>
<td>As measured by a standardised test that is given individually, the person’s mathematical ability is substantially less than would be expected from the person’s age, intelligence and education. This deficiency materially impedes academic achievement or daily living (American Psychiatric Association (DSM-IV), 1994, 315.1).</td>
</tr>
<tr>
<td>4</td>
<td>DSM-IV (online)</td>
<td>2000</td>
<td>Arithmetic academic achievement</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Test age appropriateness</td>
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<td></td>
<td></td>
<td></td>
<td>Intelligence disparity</td>
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<td></td>
<td></td>
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<td>Educational opportunity</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Educational issues</td>
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<td></td>
<td></td>
<td></td>
<td>Everyday life issues</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Absence of unrelated impairments criterion no longer included from DSM-III.</td>
</tr>
<tr>
<td>5</td>
<td>Sharma</td>
<td>1997</td>
<td>An inability to conceptualise numbers, number relationships (arithmetical facts) and the outcomes of numerical operations (estimating the answer to numerical problems before actually calculating) (Sharma, 1997)</td>
</tr>
<tr>
<td>6</td>
<td>National Numeracy Strategy</td>
<td>2001</td>
<td>Number conceptualisation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Arithmetic academic achievement criterion now superseded</td>
</tr>
<tr>
<td>7</td>
<td>Shalev &amp; Gross-Tur</td>
<td>2001</td>
<td>Children who present difficulty in learning arithmetic and who fail to achieve adequate proficiency in this cognitive domain despite normal intelligence, scholastic opportunity, emotional stability, and necessary motivation have developmental dyscalculia (Shalev &amp; Gross-Tur, 2001).</td>
</tr>
<tr>
<td>8</td>
<td>DSM-5</td>
<td>2013</td>
<td>A. Difficulties in production or comprehension of quantities, numerical symbols, or basic arithmetic operations that are not consistent with the person’s chronological age, educational opportunities, or intellectual abilities.</td>
</tr>
</tbody>
</table>
Multiple sources of information are to be used to assess numerical, arithmetic, and arithmetic-related abilities, one of which must be an individually administered, culturally appropriate, and psychometrically sound standardized measure of these skills.

B. The disturbance in criterion A, without accommodations, significantly interferes with academic achievement or activities of daily living that require these numerical skills


<table>
<thead>
<tr>
<th>No.</th>
<th>ICD-11 (proposed)</th>
<th>Year</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>9</td>
<td>Specific disorder of arithmetical/mathematical skills is a disorder in which the individual's ability on measures of these skills falls substantially below that expected for the individual's chronological age, measured intelligence and age-appropriate education. This is of a degree that significantly interferes with basic academic achievement or with activities of daily living that require mathematical skills. This assumes that the disorder is not due to acalculia, arithmetical difficulties associated with a reading or spelling disorder, or arithmetical difficulties due to inadequate teaching (World Health Organisation (ICD-11), in press).</td>
<td>2015</td>
<td>Numerosity and quantification skills (added from ICD-10) Test age appropriateness Intelligence disparity Educational opportunity Educational issues Everyday life issues Absence of unrelated impairments Alternative neurodiversities (new) Standard literacy academic achievement has been removed from ICD-10. ICD-11 still does not embrace the term dyscalculia, but has made improvements over ICD-10.</td>
</tr>
</tbody>
</table>

Table AA.1 – Definitions of dyscalculia
### Appendix B – Dyscalculia prevalence studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Terminology</th>
<th>Definition</th>
<th>Sample</th>
<th>Criteria</th>
<th>Method</th>
<th>Notes</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramaa</td>
<td>1990</td>
<td>Dyscalculia</td>
<td>Learning Disabilities Association of Canada 1996</td>
<td>Age 8-11 Grade III/IV India</td>
<td>Achievement</td>
<td>Arithmetic Diagnostic Test for Primary School Children = consistent failure even in most basic skills (qualitative assessment)</td>
<td>None (by definition)</td>
<td>6.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not co-morbid</td>
<td>R/W Test &gt;= average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lewis, Hitch, &amp; Walker</td>
<td>1994</td>
<td>Special arithmetic difficulties</td>
<td>Unclear</td>
<td>England</td>
<td>Achievement</td>
<td>Arithmetic test &lt; 85 standard score</td>
<td>64% co-morbid with reading difficulties</td>
<td>3.6%</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Discrepancy</td>
<td>NVIQ &gt; 90 standard score</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross-Tur, Manor, Shalev</td>
<td>1996</td>
<td>Developmental Dyscalculia</td>
<td>DSM-III</td>
<td>3029 Aged 9-12 Grade 4-5 Israel</td>
<td>Achievement + Conceptualisation</td>
<td>Maths &lt; 20th percentile Maths &lt; 2 grade years behind</td>
<td>26% co-morbid with ADHD 17% co-morbid with dyslexia 42% 1st degree relatives with SpLD Socio-economic factors significant with dyscalculia</td>
<td>6.5%</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>Discrepancy</td>
<td>Reading, writing &amp; spelling &gt; 80 standardised score</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Persistence</td>
<td>1 year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ostad</td>
<td>1998</td>
<td>Math disabled</td>
<td>Unclear</td>
<td>Norway</td>
<td>Support</td>
<td>Registered for special long-term help</td>
<td>51% co-morbid with spelling disorder</td>
<td>10.9%</td>
</tr>
<tr>
<td>Hein</td>
<td>2000</td>
<td>Specific disorder of arithmetical skills</td>
<td>ICD-10; World Health Organization, 1992</td>
<td>1882 Age 8-11 Germany</td>
<td>Achievement</td>
<td>DRE 3</td>
<td>Test include and make allowances for non-native speakers</td>
<td>6.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Discrepancy</td>
<td>DRT 3 spelling test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authors</td>
<td>Year</td>
<td>Study Type</td>
<td>Population Details</td>
<td>Medical Details</td>
<td>Educational Details</td>
<td>Persistence</td>
<td>Discrepancy Details</td>
<td></td>
</tr>
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<td>------------------------------------------------------------------------------------</td>
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<td></td>
</tr>
<tr>
<td>Ramaa &amp; Gowramma</td>
<td>2002</td>
<td>Dyscalculia</td>
<td>Learning Disabilities Association of Canada 1996</td>
<td>Poor Auditory Reception test results and poor visual sensory interaction with teacher</td>
<td>Poor observations and history through questionnaire</td>
<td>30.76%</td>
<td>17.97% co-morbid with writing difficulties</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Age 8-11 Grade III/IV India</td>
<td></td>
<td>Poor visual sensory interaction with teacher</td>
<td>51.27%</td>
<td>51.27% co-morbid with reading and writing difficulties</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Education</td>
<td>Poor absence record</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Motivation</td>
<td>Academic Achievement Motivation Inventory test &gt;= normal</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Support</td>
<td>Receiving extra tuition at school or at home</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Discrepancy</td>
<td>Raven matrices (IQ) &gt; 25th percentile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Achievement</td>
<td>GLAD test &lt; 2 grade years behind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mazzocco &amp; Myers</td>
<td>2003</td>
<td>Mathematics disability</td>
<td>Poor maths achievement relative to their age-matched and grade-level matched peers within similar educational environments</td>
<td>Achievemnt</td>
<td>MT &lt; 17th percentile</td>
<td>9.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Age 7-8</td>
<td>Discrepancy</td>
<td>IQ &gt; 80 std score</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Persistence</td>
<td>2 years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desoete et al</td>
<td>2004</td>
<td>Mathematics learning disability (MLD) &amp; Mathematics learning problems (MLP)</td>
<td>DSM-IV; American Psychiatric Association, 1994</td>
<td>Achievement + Conceptualisation</td>
<td>Maths test &lt; -2 sd from norm (MLD)</td>
<td>3-8%</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Grade 2-4 Belgium</td>
<td>Discrepancy</td>
<td>Maths test &lt; -1 sd from norm (MLP)</td>
<td>23%-28%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(number concepts, domain-specific knowledge &amp; maths word problems)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Resistance</td>
<td>Teacher assessed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table AB.2 – Dyscalculia prevalence studies
Appendices

Appendix C – Participant information sheet

Dyscalculia within Higher Education

Dyscalculic Student Interview Participant Information Sheet

Professor Barbara Jaworski
Mathematics Education Centre
Room A1.37
Schofield Building
Loughborough University
Loughborough
Leicestershire
LE11 3TU

Tel: 01509 22 8254 Email: b.jaworski@lboro.ac.uk

Ms Clare Trott
Mathematics Education Centre
Room A2.35a
Schofield Building
Loughborough University
Loughborough
Leicestershire
LE11 3TU

Tel: 01509 22 8258 Email: c.trott@lboro.ac.uk

Mr Simon Drew
Mathematics Education Centre
Room A1.38
Schofield Building
Loughborough University
Loughborough
Leicestershire
LE11 3TU

Tel: 01509 22 8212 Email: s.drew2@lboro.ac.uk

What is the purpose of the study?

Currently when students within higher education are identified with dyscalculia, any help they receive is based on our understanding of other learning differences such as dyslexia. No academic research has so far scientifically investigated what is the best way to support dyscalculic students at this level. This study aims to better understand this phenomenon by talking to dyscalculics themselves, and their support tutors. By
listening to the life stories of students, we hope to eventually introduce new learning and coping strategies to improve dyscalculia support practice at the tertiary level.

Who is doing this research and why?

Simon Drew, a PhD student at Loughborough University, will be conducting the research. Simon is an experienced mathematics teacher at secondary level, and is qualified at Masters level in the field of education research. There will be two supervisors on the project, Barbara Jaworski and Clare Trott. Barbara is a Professor in Mathematics Education at Loughborough University. She has worked for many years as a teacher of mathematics at upper secondary and first year university levels and subsequently as a mathematics teacher educator. Her research area is mathematics teaching and its development. Clare specialises in the provision of one-to-one mathematics support for students with dyslexia and dyscalculia. The teaching involves developing specific techniques and materials for mathematics. Clare's current research interests focus on mathematics and specific learning differences in higher education, particularly dyscalculia and the development of a first-line screener for dyscalculia. This study is part of a student research project.

Are there any exclusion criteria?

For student participation the only criteria are that you have been identified with dyscalculia by an educational psychologist or qualified assessor, and are, or have been, a student within higher education.

Once I take part, can I change my mind?

Yes! After you have read this information and you have had the opportunity to ask any questions you may have, we will then ask you to complete an Informed Consent Form. However if at any time you wish to withdraw from the study you can easily do so by just contacting the main investigator. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing. All study data relating to you will be destroyed.

Will I be required to attend any sessions and where will these be?

You will be asked to attend an interview. This will take place within the learning support centre of your institution.

How long will it take?

The interview will take no more than ninety minutes, including opportunities for comfort breaks when required.

What will I be asked to do?
In the interview you will be guided through a series of questions that ask you to talk openly about your life experiences of being a dyscalculic student. The purpose of the research is to try and understand the unique perspective that students and their tutors have, and how we in the field of mathematics research can learn from your experiences. If you give your consent, the session will be recorded, either on audio or video. If you would like to take part in the interview, but do not wish to be recorded, the researcher will be happy to only take written notes.

What personal information will be required from me?

No personal information will be required beyond your age, gender and course study. Any information volunteered during the interview will be confidential. All participants will be anonymous throughout the study, and as such you are not required to give your name.

Are there any risks in participating?

The only identified risk in participating is if you wish to discuss any stressful events within your past that you find upsetting. There is no obligation to discuss anything that makes you uncomfortable, and the interview can be stopped at any time. If you are still a student at a university, your decision to participate/not participate/withdraw will not have any bearing on your academic progress.

Will my taking part in this study be kept confidential?

All recordings and printed transcripts of interviews will be held securely in a locked location (physical and digital). Data that links participants’ names will be held in a separate secure location. All data will be destroyed after the research findings have been published, in accordance with university guidelines.

What will happen to my information?

Any information you provide from the interview will be compared with information from other dyscalculic students and their tutors, to find common themes and new insights. The data will be held in a digital format, both as an audio/video recording and after transcription has taken place. Only the three investigators named in the project proposal will have access to this data. Data will be stored securely for ten years after the publication of the results. This is to ensure that the raw data is still available to investigate any challenges to the research findings. The research data and final publication are the property of Loughborough University, however this does not affect your rights to withdraw your data from the research up to the point of publication.

What will happen to the results of the study?

The results will form part of a PhD thesis. Any learning from the study will be incorporated into good practice for dyscalculia support at higher education level. Results could also form part of a published scientific paper.
Appendices

What do I get for participating?

The final published thesis will be available to every participant.

I have some more questions who should I contact?

Any of the researchers listed above are happy to answer questions. Simon Drew would be the best first point of contact.

What if I am not happy with how the research was conducted?

If you are unhappy with the way the research was conducted, and do not feel you can raise these issues directly with the researchers involved, then please contact the university directly. Follow the link www.lboro.ac.uk/admin-committees/ethical/Whistleblowing for further information.
Appendices

Appendix D – Consent form

Dyscalculia in Higher Education

INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name

Your signature

I agree to allow the interview to be recorded.

Your signature

Signature of investigator

Date
Appendices

Appendix E – Interview schedule

**Tutor Semi-Structured Interview Schedule**

The interview will take a semi-structured format, raising the major topics printed in bold. The participant will be encouraged to talk freely about their experiences under each heading. The supplementary questions are listed to prompt the participant, if required, to explore other areas of the topic they have not considered.

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tutor background</strong></td>
<td>Can you describe your background?</td>
</tr>
<tr>
<td></td>
<td>What courses, support or self-study have you had with supporting dyscalculia?</td>
</tr>
<tr>
<td></td>
<td>How many dyscalculic students have you supported?</td>
</tr>
<tr>
<td><strong>Course impact</strong></td>
<td>What do you think are the issues that affect dyscalculic students in higher education?</td>
</tr>
<tr>
<td></td>
<td>What type of course maths is giving students difficulties?</td>
</tr>
<tr>
<td></td>
<td>- Numeracy?</td>
</tr>
<tr>
<td></td>
<td>- Algebra?</td>
</tr>
<tr>
<td></td>
<td>- Mechanics?</td>
</tr>
<tr>
<td></td>
<td>- Statistics?</td>
</tr>
<tr>
<td></td>
<td>Do students describe any difficulties with time management? Getting to lectures on time?</td>
</tr>
<tr>
<td></td>
<td>- Remembering numbers? Formulas or important figures?</td>
</tr>
<tr>
<td></td>
<td>- Talking to friends about maths?</td>
</tr>
<tr>
<td></td>
<td>- Working in a public place?</td>
</tr>
<tr>
<td></td>
<td>- Embarrassed to do maths in front of friends?</td>
</tr>
<tr>
<td><strong>Everyday impact</strong></td>
<td>In listening to dyscalculic students, what aspects of their everyday lives are being impacted?</td>
</tr>
<tr>
<td></td>
<td>- Spatial awareness? Sense of personal space? Left/right?</td>
</tr>
<tr>
<td></td>
<td>- Managing money?</td>
</tr>
<tr>
<td></td>
<td>- Time? Telling the time or taking a journey?</td>
</tr>
<tr>
<td></td>
<td>- Social situations?</td>
</tr>
<tr>
<td><strong>Learning Support</strong></td>
<td>What support methods do you use?</td>
</tr>
<tr>
<td></td>
<td>What resources do you use?</td>
</tr>
<tr>
<td></td>
<td>What have you observed about the way dyscalculic students learn?</td>
</tr>
<tr>
<td></td>
<td>How much do students contribute to the support sessions?</td>
</tr>
<tr>
<td></td>
<td>What mathematics was/was not understood in support sessions?</td>
</tr>
<tr>
<td></td>
<td>What were the students responses to the resources used?</td>
</tr>
<tr>
<td></td>
<td>What were the students responses to the support mechanisms you used?</td>
</tr>
<tr>
<td></td>
<td>Can you describe a session that went well?</td>
</tr>
<tr>
<td></td>
<td>Can you describe a session that went poorly?</td>
</tr>
<tr>
<td></td>
<td>In an ideal world, what support do you think would be helpful?</td>
</tr>
<tr>
<td><strong>Tutor reflection</strong></td>
<td>What have you learnt about yourself when supporting dyscalculic students?</td>
</tr>
</tbody>
</table>

14 March 2011
### Appendices

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What have you learnt from your students?</td>
</tr>
<tr>
<td></td>
<td>What changes would you like to see in the process of supporting dyscalculic students?</td>
</tr>
<tr>
<td></td>
<td>What would be useful advice you could offer to another tutor who is supporting a dyscalculic student?</td>
</tr>
<tr>
<td>Student wellbeing</td>
<td>How did you create a non-threatening, co-operative learning environment?</td>
</tr>
<tr>
<td>Student wellbeing</td>
<td>What can you say about the students' emotional well-being?</td>
</tr>
<tr>
<td>Dyscalculia</td>
<td>What does dyscalculia mean to you? Is the word helpful or not?</td>
</tr>
<tr>
<td>Dyscalculia</td>
<td>Can you think of any student coping strategies you have come across?</td>
</tr>
<tr>
<td>Dyscalculia</td>
<td>Can you think of any student avoidance strategies you have come across?</td>
</tr>
<tr>
<td>Areas not covered</td>
<td>Is there anything you wish to add?</td>
</tr>
</tbody>
</table>
Appendices

Appendix F – Participant biographies

This section provides brief biographical information for the fourteen participants who were interviewed for the study.

Alison

Alison was in the final year of studying a four year sandwich course in International Business at a Midlands university. She is a confident, chatty student, who excels at sports, most notably field hockey. She was identified with dyslexia at the age of 13, but was not identified with dyscalculia until her second year at university. Although she received early dyslexia support, she found this a waste of time as the sessions concentrated on phonics, with which she had no difficulty. At university she struggled with the mathematics content of the course, and had considered dropping out. She had thought that with her existing coping strategies of hard work and procedural learning she would be able to pass. She had struggled due to the unfamiliar pedagogy of higher education. She returned home and received extra tuition, and was able to pass her first year. In the second year she sought learning support help and was identified as being dyscalculic as well as dyslexic. She was given one-to-one support which Alison described as having saved her. With this support she was able to attain one of the best marks in her cohort in the end of year exam.

Figure AF.1 – Timeline graph (Alison)

Bradley

Bradley was in his final year of a four-year Arts course in Media Textiles, which included an Erasmus placement in Eastern Europe. He was identified as dyscalculic with some dyslexic tendencies during his second year as an undergraduate at a Midlands university. He also struggles with visual stress, uses a coloured overlap for reading, and suffers from severe mathematics anxiety. Working memory is a particular difficulty, and Bradley struggles to reverse digits or count backwards. He was unable to remember his birthday until adulthood.
Bradley initially wanted to become a teacher, but without a mathematics qualification he chose to do an arts foundation course, which led him on to his current studies.

Deborah was in her final year of a medicine degree at a Midlands university, as a mature student, after a successful career as both a nurse and midwife. She was identified with dyscalculia during the first year of the medical degree.

She had a negative experience at primary school, and remembers her teacher being sarcastic when she got a question correct. Her teacher also stated that she would be unable to become a nurse as she wasn’t clever enough. Deborah had used this as extra motivation and returned to the school when she qualified to show that she had succeeded.

Deborah went to college after her O levels to take a BTECH national diploma in health studies, where she struggled with statistical graphs within her physics and chemistry modules. She passed the course, however, and went on to a three year nurse-training programme.

In her twelve year nursing career she deliberately avoided departments that were mathematics-heavy. She carried a calculator around with her all the time, which was unusual then, but common now. She then decided to transfer to Midwifery, which involved an 18 month conversion course.

Deborah then decided to study medicine. She took an access course to enter higher education, and at the same time took a GCSE in mathematics, which she needed to apply. She was helped by her husband, and struggled to learn procedurally as she preferred to visualise and understand the concepts. The access course contained further mathematics topics, such as calculus. Again Deborah struggled, and received no help from her tutors. Although she had to re-sit every mathematics paper, she passed through perseverance and support from her husband.
When she graduates she hopes to specialise in pathology where there is less direct risk to patients.

**Figure AF.3 – Timeline graph (Deborah)**

**Ellen**

Ellen is studying for a Masters degree in Sustainable Management at a Midlands HEI after graduating from a Geography degree. She is quiet and lacks confidence in her own abilities, despite having developed many strong coping strategies, notably around the use of money. She had originally enrolled on a Geology course, but switched degrees due to the quantity of mathematics, notably the use of angles in describing strata. Although Geography also contains mathematics, Ellen felt that this was concentrated into a single module and not spread throughout the course. She was identified as being both dyscalculic and dyslexic while studying for her first degree, and also struggles with visual stress.

**Figure AF.4 – Timeline graph (Ellen)**

**Fiona**

Fiona is a mature student at a Midlands HEI, studying an access course that leads to a Countryside and Wildlife Management degree. She is strong-willed and vocal about the perceived injustice around the lack of support available to her. She is also open about her mathematics difficulties and not embarrassed to ask for help from colleagues. Fiona is fond of the natural world and excels in the practical elements of her course, preferring
to be outdoors than in the classroom. She returned to full-time education after careers both as a furniture restorer and a school technician. She had originally taken an HND in Conservation and Restoration straight after her O’ Levels. She was identified with dyscalculia whilst studying for GCSE mathematics at college having been prompted to seek support by a family member who was a learning support practitioner.

**Gemma**

Gemma is studying for a degree in Artificial Intelligence at a Midlands HEI. Her first year included a module on the ‘A’ level mathematics topics that would be required throughout the course. Gemma is highly intelligent, but her mathematics abilities do not match her general intelligence. Her coping strategies had previously allowed her to pass GCSE mathematics, but the level of mathematics within her degree course caused her to seek help and subsequently be identified with dyscalculia and dyslexia.

**Heather**

Heather is studying for a postgraduate teaching qualification at a Southern HEI, with a specialisation of early years. She is having significant difficulty passing the QTS tests which require both mental mathematics skills and the ability to perform mathematics under timed conditions. Heather is receiving dedicated one-to-one support to help her
through her QTS tests. She severely struggles with mathematics anxiety, and described many debilitating experiences of mathematics classrooms both as a child and an adult.

Heather found not having a GCSE mathematics qualification when she left school limiting and it restricted her choice of a tertiary academic course. After graduating, she was unable to pursue her desire to become a teacher due to her lack of a mathematics qualification, and chose to work as a child safety officer. She has since passed GCSE mathematics whilst at evening class at college, which is where she was identified as being dyscalculic.

**Figure AF.7 – Timeline graph (Heather)**

**Julie**

Julie is a mature student studying for a Masters degree in History at a Midlands HEI. She has always had a strong love of history, although she failed her ‘A’ level at school as she got confused with the chronology of events due to her dyscalculia. She has retired from a successful career as a lawyer, although she still runs a jewellery making business from home. After her Law degree, she had to pass an Accountancy qualification to qualify for lawyer status, which was the cause of significant emotional and mathematical difficulties. It was at this point that her previous coping strategies had become inadequate. Julie was identified as being dyscalculic relatively recently when she was assessed prior to her Masters course. She also struggles with visual stress in the form of Irlen’s syndrome.

**Figure AF.8 – Timeline graph (Julie)**
Linda

Linda is studying Criminology at a Midlands HEI. She left school at 16 to begin a career as a hairdresser however she did not enjoy the working environment and left after three years to pursue an alternative career. Linda then struggled in various office based jobs due to her timekeeping difficulties which contributed to her mental health issues. When her well-being improved she chose to continue her education in FE, passing a qualification in Psychology. Encouraged by her tutor to pursue HE, she passed an Access to HE Psychology course, which included a GCSE equivalent mathematics qualification. Linda was identified as dyscalculic whilst studying Criminology, where it was assessed that she had difficulties with counting and estimating numerosities.

Figure AF.9 – Timeline graph (Linda)

Maggie

Maggie is a talented sportswoman who hopes to have a career in Nutrition. She took a BTECH at an FE college before studying for an Access to HE in Science at a Southern HEI. She was identified as both dyscalculic and dyslexic whilst at FE, and her dyscalculia has been assessed as severe. She has received dedicated one-to-one support whilst in HE. She struggles with the fundamentals of mathematics and has little confidence when dealing with mathematical concepts. She is embarrassed about her difficulties, and avoids being seen when she is receiving support. She has sought an academic career out of fear of a service industry job where her mathematical difficulties will be exposed.

Figure AF.10 – Timeline graph (Maggie)
Appendices

Nancy

Nancy is part way through a PhD in Fine Art at a Northern HEI, having had to postpone her studies due to financial issues. She is currently working as a learning support practitioner at the same HEI. From school she enrolled on an Access to HE Art course, which led to a degree and then a Masters degree in Fine Art. She also took a PGCE in Higher Education, which did not require a mathematics QTS test. In between studying she has worked in the service industry, where her severe mathematical difficulties led to her resigning from jobs as she could not cope with the numerical demands. In her Art career her needs for mathematics has been minimal, but in everyday life she struggles with money and time and is supported by her husband who provides practical assistance. She was identified as being both dyscalculic and dyspraxic whilst studying for her Masters. Her dyspraxia gives her co-ordination issues which have prevented her from learning how to drive.

Olivia

Olivia has recently completed a degree in Management Science at a Midlands HEI, and has begun a career in administration for a learning support centre. She left school during her ‘A’ Levels and supported her boyfriend while he was at University. She then continued her own studies by applying for an Access to HE course which led to her degree. Olivia has superb organisation and presentation skills which she has used as a coping strategy throughout her academic and vocational careers. Olivia is reliant on her mobile phone which she uses to set regular alarms for her daily activities. She was identified with dyscalculia at her HEI, whereupon she received dedicated one-to-one support.
Quentin

Quentin is a mature student studying for a Masters degree in Psychology at a Scottish HEI. He took his first degree in his mid twenties after a career as a painter and decorator. He had originally hoped to study Art, but his severe mental health issues had meant that accessing HE had been problematic. Quentin was initially identified as being dyscalculic whilst attending a ‘Return to Education’ course. He has severe mathematics anxiety, and struggles to deal with everyday mathematical issues. Quentin finds time and travel particularly difficult, and chose to live next to the train station to limit the stresses of timekeeping.

Rebecca

Rebecca has just graduated from a Nursing degree at a Scottish HEI. Her initial attempt at the degree was aborted when she was identified with dyscalculia and advised that she would not be able to pass due to the demands of drug calculations. In the meantime Rebecca continued to work in the care sector and was later encouraged by her doctor to reapply to continue her Nursing degree as dyscalculia should not be a barrier to academic success and she was entitled to support. Through hard work and determination Rebecca passed her placements and qualified as fit to practise. Rebecca has received dedicated one-to-one support in her second attempt at her HEI.
At school Rebecca’s parents were concerned about their daughter’s progress in mathematics and regularly contacted the school, always to be informed that her progress was normal. When Rebecca left school she studied hospitality at FE and then worked in a hotel, but her mathematical difficulties meant that she could not cope with managing the customers’ bills and she left to pursue Nursing. Rebecca has kept a scrapbook of her experiences with dyscalculia, including letters from various official agencies and newspaper cuttings.

Figure AF.14 – Timeline graph (Rebecca)
Appendix G – Sample code prevalence diagrams

INTERSECTION OF CODES
BRADLEY, DEBORAH & FIONA

BRADLEY

DEBORAH

FIONA

64

23

29

38

20

43

54

332
Appendices

ORBIT DIAGRAM – CODE INTERSECTIONS OF 6 STUDENT

Intersection Colour Key
1 student
2 students
3 students
4 students
5 students

Student Name Key
A = Alison
B = Bradley
D = Deborah
F = Fiona
H = Heather

combinations
combinations
Appendix H – Postgraduate certificate course details

While researching my PhD, I attended the MLSC’s Postgraduate Certificate Course for Mathematics Support and Dyslexia/Dyscalculia in FE/HE, as a non-matriculated student. This allowed me to access lectures and participate with other students in seminars and group discussions. This course was aimed at existing learning support professionals, or graduates with HE mathematics knowledge wishing to teach students with SpLDs. The course had British Dyslexia Association (BDA) accreditation at the level of Approved Teacher Status (ATS HE/FE) (Loughborough University, 2012).

The course comprised five modules considering issues such as the difference between dyscalculia and dyslexia with mathematical difficulties, screening and identification, mathematics anxiety, using students’ strengths as a teaching strategy, alternative sensory learning, and the vulnerable student.

The course was invaluable in gaining background information on an array of topics that influence dyscalculia identification and support, and provided me with source material for the literature review sections of my thesis. Another major benefit of the course was the opportunity to network with other students, to discuss experiences and share best practice. I also gave two talks to the class explaining my work and the progress I had made. Two of the student participants in my main study were referred to me by a colleague on this course.

I did not attend the final module as it involved practical work with a single student in a learning support setting (which I did not have access to at the time), although the skills I acquired on the course had a practical application as part of my secondary research method of working one-to-one with two participants. This was particularly relevant in the context of differentiating between the mathematical difficulties encountered by the neurodiverse students. I was able to identify how the students’ interactions with mathematics differed, and assess the strengths and weaknesses of the students’ existing learning approaches. The course content on multi-sensory techniques to aid working memory was beneficial, particularly with dyslexic student Ian (see appendix K), where I used colour and images to correspond to his strong visual skills. Mathematical confidence was another major element of the course that had a direct bearing on my support sessions, as I realised how essential it was to address the mental well-being of the student to create a collaborative partnership in a relaxed environment to allow for effective mathematical learning to take place.
<table>
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<th>Module Title</th>
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| Dyslexia and Dyscalculia: Identifying the Problem| This module was designed for those students who are comfortable with higher level mathematics and wish to develop a better understanding of learning support and SpLDs. The module included:  
  The nature of dyslexia and how this affects the academic and everyday life experiences of FE/HE students.  
  Current debates on the nature of dyscalculia and the effects of dyscalculia on FE/HE students.  
  The specific problems that visual stress can cause in working with mathematical material. Activities included using software to experience the various types of visual stress that have been recognised, to see how this would affect engagement with mathematical tasks.  
  An introduction to neuroscience theories on dyscalculia and dyslexia.  
  The screening and assessment processes for dyslexia and dyscalculia, and familiarity with the use of various screening tools. This included practical activities of trialling and assessing a number of screening processes, both individually and in groups.  
  How to talk sensitively to students about the identification process and how to use the assessment data to assist in the planning of ongoing support.  
  How to manage an effective collaborative working relationship with other agencies and services providing support and advice to students with SpLDs. |
| Mathematics Confidence and Dyscalculia: Identifying the Problem | This module was run parallel to the previous one, and was designed for students from a learning support background who wished to develop their mathematical skills. The dyslexia aspects of the previous module were replaced with mathematical seminars to increase the students’ own confidence in using and applying mathematics and statistics. |
Using Strengths for Teaching Mathematics and Statistics

The module included:

- The differences between teaching dyslexic and dyscalculic students, and a basic understanding of the learning styles of students with various SpLDs, and how to create a student-led, negotiated learning environment. This included exploring case studies to try and recognise what the strengths and weaknesses of students might be.
- An understanding of how working memory affects learning and how the use of multisensory techniques can positively impact upon working memory, including tasks to design multi-sensory learning resources for dyslexic and dyscalculic students.
- Awareness of the benefits and limitations of assistive technology, including demonstrations of available software and devices.

The Vulnerable Student

The module included:

- The emotional issues that may arise alongside dyslexia and dyscalculia.
- Research and practice regarding mathematics confidence and exam stress, to provide an understanding of mathematics confidence and ways of working with students with mathematics confidence issues.
- A basic theoretical understanding of the dynamics of the support/counselling relationship. Awareness of risk and protection factors contributing to dyslexic/dyscalculic students' educational success or failure.
- Communication of the outcomes of screening and assessment with students in a sensitive and meaningful way.

Mathematics and Statistics Teaching Practice

This module covered the practical application of the skills learnt in the previous modules. This included screening for dyslexia, dyscalculia and visual perceptual difficulties with an HE/FE student, and the preparation, delivery, evaluation and reflection of one-to-one learning support.

Table AH.1 – Module contents
Appendix I – Dyscalculia in higher education survey

Early in my postgraduate career I assisted in a study to capture the current ‘state of play’ in HE with regard to the identification and support of dyscalculic students. Clare Trott in the Eureka Centre for Mathematical Confidence, through anecdotal discussions with her peers at other institutions, had highlighted inconsistencies in implementing a ‘fit for purpose’ approach to supporting dyscalculia in the tertiary sector that encompassed adequate policy, awareness, reasonable adjustments and provision of support. She proposed that a national dyscalculia survey could provide a ‘snapshot’ of the current HE situation with regard to dyscalculia prevalence and support provision, and provide quality evidence of the ongoing situation.

The proposal for this study was serendipitous for my own work. Not only did it provide valuable secondary data about how other institutions operate, it provided information on the quantity and distribution of potential participants. This allowed me to target some communications to institutions with strong dyscalculia support practice and previously identified students.

The questionnaire was written using the Bristol Online Survey software and the requested data included the dyscalculia screening process, the number of identified students, and anonymous details of student profiles, e.g. course, neurodiversity, timing of identification and type of support required.

The survey went live in January 2011, with an email being sent to various JISCmail groups, describing the purpose of the survey and inviting participation.

Clare and I presented the findings at both the 8th BDA International Dyslexia Conference and the ADSHE Network Conference in June 2011, and a joint-authored paper (Drew & Trott, in press) was submitted to the BDA journal publication Dyslexia.

As the full results of this study have been submitted for publication, this is a summary of the findings and how they have contributed to this research study.

Screening for dyscalculia

The survey asked a question regarding the type of screening process used to identify dyscalculia, which was answered by 37 of the 39 responding HEIs. The results were categorised as a diagnostic interview (DI), a dyscalculia-specific test (DysC) or a dyslexia-specific test (DysL), or combination thereof. The most common approach used by over 24% of HEIs in the study (n = 9) was a combination that considered all three
screening tools, that would allow for the identification of both dyscalculia and dyslexia with mathematical difficulties. Over a third of respondents (n = 14) did not use a screener designed to recognise dyscalculia. Using a Mann Whitney U non-parametric test (p = 0.005 < 0.05), it was shown that institutions that had employed a DI had identified significantly more dyscalculic students.

The caveat to these results on screening is that at the time of the study, there were no age appropriate dyscalculia screeners available. With the advent of new software such as Loughborough University’s DysCalculiUM (Tribal, 2010) this situation should improve.

In the interviews with my participants, screening was not an issue that was discussed in great detail. This was not a surprise as the endpoint of the identification process is what was relevant to the student, rather than the mechanism to achieve this.

**Number of students**

The survey asked for the number of dyscalculic students registered with each HEI. The median number of dyscalculic students from the survey was three per institution, although there was a report of 76 students having been identified at one university, IID 9 (see figure AI.1). It was difficult to interpret such an outlying result. Although dyscalculia is under reported due to the lack of awareness and assessment opportunities (Butterworth, 2003), the IID 9 result was so atypical that it seemed likely that many of these students were dyslexic with mathematical difficulties and had been misidentified as dyscalculic, as they had been identified with a co-occurrence.

The percentage of identified dyscalculic students within the survey population was calculated to be 0.04%. There are likely to be dyscalculic students who have not sought help and are coping with their learning difference, so this is not likely to be a true reflection of the total HE percentage. In 1994-1995 the percentage of students with dyslexia entering HE was 0.48%, by 2006-2007 it had risen to 2.82% (Higher Education Statistics Agency (HESA), 2012). Note that 2007 was the last year that the Higher Education Statistics Agency recorded dyslexia distinctly from other SpLDs.

In terms of my research the survey showed how difficult it would be to find participants. A quarter of the total number of UK institutions had only reported on 154 students (with many of these possibly misidentified dyslexic students with mathematical difficulties), so the national pool of students available was worryingly small. Therefore finding enough participants for my study was a concern. However if the low numbers did indicate the failure of dyscalculic students to reach HE, then my research could potentially reveal some reasons for this through the exploration of the students’ educational experiences.
Identification of dyscalculia

The survey showed that a quarter of dyscalculic students arrived in HE with a pre-existing identification (see figure A1.2).
Since the Butterworth screener was published in 2003, each Local Authority has had the option to test for dyscalculia in primary schools (Dyscalculia Centre, 2011). Studies such as this, aim to raise awareness and encourage learning support centres to reflect on their own dyscalculia provision.

Official identification is an important theme of my study and explored in depth. No participant in my study was identified before post secondary education, which led to conjecture on whether an earlier identification would have made a difference.

**Subject areas**

When considering academic subjects, 34% (n=51) of the students had chosen courses such as nursing and midwifery, which are classified as ‘subjects allied to medicine’ by the Universities & Colleges Admissions Service (UCAS). The resultant percentage figure for this subject area was nearly three times greater than for any other (see figure AI.3). The validity of the high prevalence for healthcare courses is supported by anecdotal evidence of medical professionals struggling with drug dosage calculations, monitoring fluids and reading charts (Institute of Medicine, 2000; Sabin, 2001; Thomas et al., 2001) which could be as a result of dyscalculia (MacDougall, 2009; Kirk & Payne, 2012).

![Bar chart showing the percentage of dyscalculic students by subject area](image-url)
As finding participants for my own study was difficult, I was not able to select a wide variety of subjects studied by students. I had hoped that a good cross-section of degree courses would be represented, to provide a differentiated view of HE life. Although my sample has produced a wide selection of courses, it was concerning that the ‘subjects allied to medicine’ category, so much the focus of the survey, was only partly represented by a single medical student who was an ex-nurse. This led to an active campaign to recruit a current nursing or midwifery student to help explain some of the issues raised within the survey.

**Neurodiverse profile**

Within the survey sample, 73% (n = 105) of the students had a co-occurring identification of dyslexia. As there is ambiguity about the distinction between some aspects of dyslexia and dyscalculia (Trott, 2010c), it is often difficult to judge a true a figure for this ‘overlap’. Just over 33% (n = 48) of the sample had also been identified with dyspraxia (Developmental Coordination Disorder (DCD)). Dyscalculia in isolation was reported in just 15% (n = 21) of the sample.

The neurodiversity of my own participant sample showed an equal mix in terms of dyscalculia-only and dyscalculia with a co-occurrence of dyslexia. The differences between these two neurodiverse profiles were highlighted by one of my chosen data collection methods, where I supported both a dyscalculic-only and dyslexic-only HE student to try and distinguish between the neurodiverse nature of their mathematical difficulties.

Two students in the sample were officially identified with a co-occurrence of dyspraxia, so some analysis of this and how it contributed to their mathematical difficulties was possible within my study.

**Provision of support**

The provision of one-to-one support to dyscalculic students was very mixed, but 59% (n = 16) of the HEIs employed a mathematics specialist as a support tutor (unrelated to SpLDs) (see figure AI.4). This potentially leaves many students without access to the support they need and are legally entitled to. Many institutions that did not provide this service commented that this was a shortcoming.
Figure AI.4 – Number of institutions by support provision
Appendices

Appendix J – Pilot interviews

To trial the interview process, three pilot interviews were performed (Olivia, Sally and Paulette). This served to review my choice of questions, gain practice in the use of the interview method, and to detect any early evidence that might shape my research design. As this was partly a test of process, it was not essential that my pilot students were officially identified as dyscalculic, although it was imperative that they had all experienced mathematical difficulties. The students were recruited with the help of my supervisor through local network opportunities. Both Olivia and Paulette had been identified with dyscalculia, whereas Sally was dyslexic with mathematical difficulties.

The pilot interview schedule was developed to ensure that my research questions were covered. It should be noted that at this point, the scope of my research was wider and included aspects of the students’ lives outside of HE, such as childhood and work experiences, that have since been excluded due to manageability. These themes have been coded but not analysed.

Ethics approval had been granted before the pilot process took place. One aim of the pilot was to trial the dissemination of ethics information to the participant, to ensure they were fully aware of the interview process and their rights within that process, for example the opportunity to withdraw at any time. I observed how the students engaged with the materials provided, i.e. the participant information sheet and consent form, and how long the process took to discuss the administrative matters.

Interview process

The three interviewees were diverse. Olivia was bubbly, extrovert and chatty, reminiscent about her struggles from a position of hindsight. Sally, in contrast was stressed and upset, and talked honestly and at length about how she felt a victim in an unfair world. Despite her vulnerability she was resolute in her determination to tackle various injustices and to succeed in her chosen career path. Paulette was guarded, and although polite and personable, did not reveal as much about her mathematical issues. She appeared to be in denial, as her account contradicted information from her tutor.

Olivia’s interview lasted for 90 minutes, and could have continued for longer such was the wealth of discussion. I chose to bring Sally’s interview to a close after 50 minutes due to concern for her well-being. Sally had become upset from her recollections, and although this was providing rich data, it was a risk to the well-being of the student. The
interview with Paulette lasted one hour, and had come to a natural conclusion in that time.

**Learning for the interview process**

From the perspective of process, I was pleased with the quality of data obtained, but had reservations about the order of my questioning. The schedule began with an inquiry regarding the student’s course, which in the first two interviews had resulted in a stream of emotional detail about university-related issues. When I then asked about the childhood experiences, the chronology felt misplaced, as if the story was in reverse. Even though the students were encouraged to dictate the direction of the interview, my questioning schedule felt unhelpful. I considered starting the interview with the childhood questioning, but my supervisor was concerned that this could immediately touch upon some difficult past experiences, and would be an uncomfortable and inappropriate place to start. For the third interview I kept the same order of questioning, but initially asked the student to talk generically about the course details, and some positive experiences. This was to build a rapport with the interviewee and gain a level of trust, before raising any potentially difficult childhood issues.

In the second interview, Sally meandered in her recollection of important life events, and although I was delighted that she was taking the initiative, it made it difficult to track the coverage of the interview and to ensure that my research scope had been addressed. From this experience I developed a tick-sheet (see appendix L) that used single word descriptions of the points I wished to raise, and this was trialled successfully in the third interview.

Sally’s negative accounts of past experiences caused her distress within the interview, and were a valuable reminder of how the student’s well-being must be paramount. From this I became aware of the strong possibility of similar reactions within my main study, and began to consider how I might deal with such emotional outbreaks during interviews. In actuality, I did not witness the same amount of distress in any of the subsequent interviews, although I did witness tearful recollections that needed to be managed sympathetically, notably from Ellen, Quentin and Rebecca.

Whilst I felt my interview questions had facilitated greater insight into Olivia’s and Sally’s stories, I had the sense that Paulette’s story remained untold. I was unsure at this point whether this was a failure of my interview process, or whether I would have to accept that I will be unable to capture some stories in the same amount of detail. I decided to interview her again as a participant in the main study (after she had recently taken part
in a statistical research task as part of her undergraduate dissertation), but the results were the same. I ultimately decided to exclude her from my study.

The consent forms worked well (see appendix D), and did not require any modifications. My initial attempts at disseminating the ethics information were cumbersome, but with each interview I improved my technique and the completion of administration tasks became more efficient, allowing for greater interview time.

Early evidence

Both Paulette and Olivia described events that had been fortuitous in helping them achieve their grade ‘C’ in GCSE mathematics. For example Olivia had an injury that prevented her from taking one of her weaker papers, and so the examination board averaged her marks from another paper and her coursework. As meticulous organisation and presentation was Olivia’s main strength, the higher weighting to her coursework was a distinct advantage. As this pilot process had revealed some unusual stories around the attainment of the required ‘C’ grade, I decided to add a specific question to ensure the GCSE timeframe was explored adequately (although this theme was later removed from the study to focus upon HE issues).

With regard to students’ coping mechanisms, rather than a single mechanism emerging from the data, different strategies became evident. Olivia in particular employed many techniques; organisational skills to cope with her difficulty in tracking the passage of time, spreadsheets to mediate her inability to manipulate numbers, meticulous presentation to gain high marks in mathematics coursework, and social skills to create a reliable support network of friends. The other students’ coping mechanisms were more related to learning styles; Sally worked slowly and struggled to retain number facts, but was able to use repetition techniques as a way of triggering her memory to recall statistical information, whereas Paulette employed a strategy of ‘cramming’ to try and overcome her long-term memory issues. In everyday life they both ensured they had a calculator with them at all times, which turned out to be a common finding (although most of the dyscalculic students used smart phones). From this early evidence, it appeared that a common coping mechanism was the ability of the student to transform their own talents into a means of neutralising the disadvantage; using personal strengths to overcome the weaknesses. This highlighted the need to capture overt coping mechanisms within the interview schedule wherever possible, but in reality many of the coping mechanisms may be less obvious with participants unaware of their own strategies.
All three students admitted to failure to appreciate the extent of mathematics in their course when choosing their degree. Sally had already dismissed one option due to the ‘excessive’ mathematical content, and yet still enrolled in a course where statistics caused her stress and considerable difficulty. All the pilot participants had a realistic expectation of some mathematics, but had misjudged the amount and level of mathematics that would be required. This proved to be a common theme within the main study interviews.

Academic isolation was a topic touched upon by all three students, which resulted in the need for extra time to work and the student choosing solitude in order to concentrate. This informed my interview schedule, and I asked the dyscalculic students about learning style and their optimum environment in which to study.

They were unanimous in expressing their identification with an SpLD as a positive event. They told similar stories of confusion and self-reflection at school; failing to grasp their difficulties when they performed so well in other subjects.

These pilot interviews were my first opportunity to compare the mathematical difficulties of dyscalculic and dyslexic students. Olivia and Sally were very articulate in describing the nature of their difficulties and the differences were very apparent. Both had mathematical anxiety, although Olivia’s was based around more the appearance of numbers, whilst Sally’s was related to the engagement with mathematics generally. Olivia could recite terms and mathematical ideas from memory, but had no understanding of them conceptually, relying on a procedural approach to complete tasks. She did however have strong visual skills, which aided her memory and helped her to succeed in shape and space questions. Sally struggled with mental arithmetic and was slow to process mathematical information, such as reading from a graph. She also struggled to organise and sequence questions, and made mistakes by transposing digits. These difficulties are consistent with dyslexia with mathematical difficulties. Pauline was unable to give the same clarity around her difficulties, and it was difficult to interpret how her mathematical practice was affected by her dyscalculia.
Appendices

Appendix K – Learning support reflections

As well as the interview data which was my primary data, I used reflective accounts of tuition sessions to provide another source of information. This is not a deep analysis, but a background secondary source of data for me to draw upon where possible to back up the claims of the participants during interview. This data was not coded. The support sessions were arranged with two participants, Fiona and Ian. The purpose of these sessions was to help me better understand the differences between dyscalculia and dyslexia with mathematical difficulties, through personal experience.

Fiona was seeking one to one support as her HEI was unable to support her needs. She had been identified as dyscalculic, and her learning support department had asked the Mathematics Education Centre at Loughborough University if they could help. Twelve hours of support was provided over three days, and Fiona consented to the sessions being recorded for research purposes. This support took place at both Loughborough University and Fiona’s own HEI.

Ian was a dyslexic student studying for a degree in Construction Management. His university had contacted Loughborough University enquiring about one-to-one support for his mathematical difficulties, to help him pass a re-sit of a mathematics module examination. Nineteen hours of support were provided at Loughborough University and Ian agreed for the sessions to be recorded and used for research. Note that as a dyslexic-only student, Ian was not interviewed for this study.

The content of the sessions was directed by the students. As Ian was revising for a re-sit of a mathematics paper, his sessions involved extensive work with past papers. With Fiona, the sessions’ content varied between statistics required for an assignment and general numeracy with which she felt she needed help. A summary of these support sessions was published as part of a paper by Trott et al. in 2012.

Reflection on working with Fiona

Fiona was entitled to one-to-one support as part of her needs assessment for dyscalculia, but her HEI was unable to provide a suitably qualified tutor. For a short period of time Loughborough University agreed to help support Fiona, and while I was supporting her, she agreed to take part in my research.

For her Wildlife and Countryside Management course, Fiona’s mathematical needs were mostly centred on statistics. Together we worked through two assignments, one involving flora in a designated area of woodland, and another analysing owl pellets for
the concentration of rodent remains. She had been given a prototype solution by her lecturer to help her understand the various steps required. This offered a useful basis for me to ask open questions about what the assignment was trying to achieve, and to better understand the nature of her difficulties.

Fiona requested help with Excel spreadsheets which she had been told to use as a statistical inference tool. Although she had been to a number of Excel workshops, she was still struggling to understand the nature of Excel as a software package. I found that she also struggled with general computer literacy, e.g. how to use a spreadsheet, although this seemed likely to be the result of being a mature student with less previous experience of computers, rather than due to her dyscalculia. I offered support to help her become familiar with the interface of Excel, some of the rationale behind various statistical tests, and how to interpret the results.

Fiona seemed ‘unusual’, compared to my previous experience with dyscalculic HE students, in that she wanted to learn conceptually, and understand the rationale for various processes. She appeared extremely perceptive and open, and always questioned every step, trying to understand the conceptual reasons for the mathematical methods I was demonstrating. This was unexpected as the other participants generally had shown no desire to understand the reasons behind a process, just how to produce the correct result. When Fiona did follow a procedure, she was usually successful and learned the methods quickly, but she would continually question why she was performing a particular action and was hesitant, even when she was able to produce the correct answer. My impression was that Fiona’s need to understand might be a personal trait rather than a characteristic of dyscalculia, as this was not a trait that I had previously seen related to dyscalculia. The other dyscalculic students in my sample described conceiving mathematics purely as the means to produce a correct result, but Fiona needed some level of conceptual understanding too, which in some ways was a disadvantage as it slowed her progress. But when she was able to grasp a mathematical concept, she was able to apply her new understanding to a variety of scenarios.

Fiona always questioned every suggestion and was curious, allowing for an easier formative assessment for learning as I was able to establish what she understood quite easily. I found myself trying to relate every new concept to a contextual explanation, and each new idea that I introduced needed concerted time aside to explore before we could introduce it into the desired solution. Fiona wanted to learn conceptually, and as a teacher, I adapted my strategies to help her learn in this way. Progress was made, albeit slowly, and Fiona appeared to appreciate having a tutor who was patient and sympathetic to her needs. When I taught Fiona some mathematical concepts such as
calculating averages, she became more comfortable in adopting some procedural methods, even when she was unable to understand the justification for them, or how they worked. Therefore, some conceptual teaching was valuable for Fiona, but only as a way to help her gain confidence to trust more procedural strategies, as the rate of progress of conceptual learning was too slow for the time available.

I tried to explain to Fiona how the use of visual presentations such as graphs can be helpful for some students. Whilst Fiona could understand simple graphical ideas such as comparison of bars in a bar chart, she mostly felt that the numbers in data tables and graphical axes failed to represent the underlying subject matter. She did not view the subject matter as quantitative, and found it difficult to assign numbers such as frequency counts to the inherent flora and fauna. Fiona described a strong need to relate to data through her own experiences. When she had collected the wildlife data from the first exercise herself, she was much happier and felt she had an understanding of what was going on through using her own senses. She was confused by comparable data that had been gathered by other students as she was not the person to have collected it and visited the setting personally. Fiona felt she was able to get a much better understanding of one of her countryside locations by observing the wildlife rather than translating the information into numbers such as counts or measurements. She struggled to quantify the real world and represent it graphically. Unlike other students, who often find visual representations of data helpful to understand trends, Fiona felt it was confusing and took her data away from her so that she no longer recognised the environment she had observed within the numerical data.

Fiona had great difficulty in organising her data in tabular form. The assignment setter had formulated questions in such a way that the data needed to be organised in a particular manner to allow for statistical analysis. Fiona however, had chosen a different way to arrange the data although her organisation was mathematically correct. This was an example of where a simple procedure could not help Fiona understand that she had to order her data in a way to match the requirements of the question, but instead she needed more in-depth knowledge of how the data organisation would affect the various queries that could be placed upon it. A more complex procedure would be required that looked closely at the use of words within the question to formulate the correct approach. Once the data was rearranged, Fiona picked up the procedural methods quickly and was able to produce accurate results. Understanding how the layout of data tables was imperative to the inferential statistics took a lot of time, and I am not convinced that Fiona would be able to repeat a similar task that involved the same level of data interpretation.
Fiona was able to follow the processes to use statistical inference tests, once she became familiar with the Excel interface. She was well organised and made careful notes about which buttons to use and what data to interrogate on the resulting report. Unlike Ian, (see next section), Fiona’s handwriting was neat and her work well documented into sequential steps. Her folder of work was also well organised with a colour-coded, indexed breakdown of each topic with her lecture notes, assignments and supportive material.

**Reflection on working with Ian**

Ian needed support to retake his first year mathematics module examination for his Construction Management course. The curriculum contained A level mathematics topics, but the questions were often complicated and involved multiple steps combining more than one concept to derive an answer. Each week, Ian and I would attempt a past paper together so I could familiarise myself with the level and syllabus required, and the contextual framework of the questions. As problematic mathematical concepts arose, these were studied in isolation by creating progressively more difficult sample questions to allow Ian to gain confidence in his own abilities and some new coping strategies.

Ian displayed an aptitude for questions requiring visual understanding, for example finding areas or volumes of compound shapes. He was able to visualise how the addition or subtraction of shapes could create more complex constructions, and it was only his difficulties with the accurate manipulation of algebraic formulae that impeded him from completing this type of question. Ian also had a good understanding of economics, and was able to understand financial concepts such as compound interest. Although he was able to find effective strategies to answer these questions, his chosen methods were often time-consuming and prone to error. This, to me, emphasised one difference between dyslexia and dyscalculia, which was how Ian was able to grasp the meaning of the mathematics and understand the numerical principles, but was unable to put in place efficient and timely methods to solve them. When Ian tried to access quicker alternative methods, he clearly demonstrated that he understood the new concepts but it still took repeated efforts for him to employ the new strategies without error, and reach a level of automation.

Ian was prone to making mistakes due to the disorganisation of the layout of his work, and illegible writing. He would often write an incorrect symbol or digit, even if he had verbalised the mathematical statement correctly. Algebra was especially difficult for Ian, who had little confidence when manipulating algebraic terms. Ian had been taught algebra using procedural methods which he had since forgotten (indicative of poor memory and dyslexia), and therefore no longer had any understanding of the purpose of
algebra or how to use it. Much of my time spent with Ian was dedicated to algebraic manipulation; creating formulae and rearranging equations. Ian was shown how algebraic variables represent real numerical measures in a variety of situations, and how by applying specific values, an equation can be formed. This was demonstrated using real-world examples to create the same equations, in order to show how the abstractness of algebra relates to real word problems.

For expanding brackets and solving quadratic equations, I used the crossing eyebrows/double chin approach. I used this visual method and humour to help Ian memorise a procedural method. Each line (eyebrow or chin) was coloured when the multiplication had taken place, to keep track of the steps in the procedure. With the use of coloured marker pens to shade each eyebrow or chin when the multiplication had been performed, Ian was able to keep track of the steps required. I also used the coloured marker pens to highlight each separate term as it was created at each stage. Incorrect allocation of signs was one of the most common errors that Ian made, so colour-coding the positive and negative terms was helpful for him.

The retention of mathematical knowledge in long-term memory was also an issue for Ian. Within one session he would demonstrate a procedural understanding of the mathematical topic, but this knowledge would no longer be in situ by the following week. Number bonds and times tables were also a weakness, but this was not a major issue as he was able to use a calculator in his examination, which he could operate accurately and usually without error. I encouraged him to carry on using the calculator, as the priority for the sessions was for Ian to pass his re-sit examination, rather than to improve his ability to remember number facts.

Repetition, or over-learning, of questions proved necessary for Ian to retain his progress between sessions, due to his dyslexia-related poor working memory. Various strategies were employed to help Ian retain information. It became essential to revisit topics repeatedly, and never assume that the subject had been sufficiently covered even when Ian answered questions correctly. Revisiting previous work at the beginning of each new session was vital to consolidate learning, and to judge how well Ian was able to absorb new ideas. It was necessary to continually re-test topics over a number of sessions, to judge progress, and modify learning approaches when knowledge was not being retained. This led to more emphasis on conceptual understanding, despite the tight deadline, as Ian was able to retain this type of learning more successfully. Where Ian had been employing an inefficient method for attempting to solve an equation, for example, calculating compound interest over a long term by working out each year separately, he was shown new, faster, methods which he was able to use repeatedly and
independently. The new strategies had to be explored conceptually, showing why they were effective, and how they would result in a more efficient calculation process. A procedural explanation appeared less likely to be retained in long-term memory across sessions as Ian wanted to understand conceptually.

Ian found this iterative process frustrating, as he wanted to keep moving on to new topics to cover the syllabus knowledge required to pass the re-sit paper. As his tutor, I felt that skimming over the curriculum to obtain maximum coverage could result in Ian retaining little or no knowledge for the examination. Together we discussed the nature of his dyslexia and decided a better strategy was to choose a subset of topics and repeat questions on these until evidence of solid progress could be seen across sessions.

A key strategy in supporting Ian was to encourage him to work more methodically in presenting his mathematical arguments. When Ian and I worked through a question together to a correct solution, he would acknowledge that he understood the mathematical content, but did not recognise that the clarity and legibility of his working was a key component. Ian would quickly fall back to his previous strategies, rather than adopt the slow methodical approach that had worked previously. This raised the question of how, as a tutor, I could encourage him to adopt the organisation procedures independently. I used colour marker pens to illustrate the working, and notate the steps that needed consideration. I had hoped that Ian would adopt the coloured markers independently, but he seemed reluctant to do so. Initially he did not appear to see the value of organising his work and continued to try his own strategies. He was slow to adopt the new techniques and repeated his previous mistakes. I persevered by notating his work, colouring each step differently, and adding ticks, crosses and arrows to illustrate each decision or movement of a term across an equation. This strategy worked as he could then see the benefits of this notational approach within his own work. After a time, he began to adopt these strategies, and the accuracy of his work improved.

Time was spent helping Ian work through multi-stage problems, learning how to break a problem into manageable parts. Most of the examination questions were complex and required the calculation of an intermediary variable, which was not initially expected by Ian, who was searching for a single step solution. By learning to plan questions and recognise what information he knew, and what was unknown, he became more confident in recognising strategies to tackle the examination questions. Poor planning is known to be a common difficulty with dyslexic students and assistance in this area was shown to be beneficial to Ian.
## Appendix L – Interview tick sheet

### STUDENT INTERVIEW OBSERVATION SHEET

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### Field Notes

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Appendices

Appendix M – Neuroscience

Most of the current research into dyscalculia has been in the domain of neuroscience. This follows the medical model that explores the reasons why dyscalculia occurs and attempts to find ways to detect it using scanning technology rather than through assessment of mathematical difficulty.

Neuroscientists conjecture that a faulty region or regions of the brain have caused dyscalculia, and by identification of this region, future dyscalculia could be detected using brain imaging scans. This work is, however, is in its infancy as researchers are still mapping the mathematical cognitive processes in neurotypical individuals (Kauffman et al., 2011). Current research utilises two differing techniques to image the brain using magnetic resonance imaging scanners (MRI): structural and functional imaging.

Structural imaging

Structural imaging examines the differences in internal structures of the brain and correlates this with individuals of varying mathematical abilities. Researchers use the MRI machine to apply a strong, permanent magnetic field across the region of the brain to be studied, which aligns nuclei in the brain and measures the energy that is emitted. By associating atypical mathematics performance with variances in white matter, researchers believe that they can identify the regions of the brain that are responsible for performing mathematical tasks. White matter is a part of the brain that contains nerve fibres and is responsible for the speed of nerve signalling. Although research of this type (Barnea-Goraly et al., 2005; Rykhlevskaia et al. 2009) has produced conflicting results, there is “some level of consensus in the findings from both typically and atypically developing populations that individual differences in numerical and mathematical skills are related to white matter microstructures in the left parietal lobe.” (Matejko et al., 2012, p605)

Functional imaging

Researchers also use functional imaging (known as fMRI) to discover which parts of the brain are active as individuals perform mathematical tasks in real-time. Brain activity can be monitored by the increased flow of blood, as there is a known relationship between cerebral blood flow and neuron activation. The MRI scanner is able to detect the change in magnetic properties between oxygen-rich and oxygen-poor blood to create a measure of brain activity. The disadvantage to this approach is a timing issue, as it is unclear how
much delay would be seen between the stimuli for mathematical tasks and the brain activations.

Functional imaging work that has looked specifically at children with and without dyscalculia has “revealed a largely inconclusive picture” (De Smedt et al., 2013, p51). Price at al. (2007), Kaufmann et al. (2009) and Mussolin et al. (2010) have together highlighted six regions of the brain that show stronger activity in control children than dyscalculic children when undertaking symbolic and non-symbolic mathematical tasks, and seven regions that are more prominent in dyscalculic children. Kucian et al. (2006) found no contrast in brain activations between these two groups.

**Physical brain**

The mapping of the dyscalculic brain is still an ongoing exercise for neuroscientists, but there is agreement amongst many researchers that the intraparietal sulcis and nearby regions have a strong bearing on dyscalculia (De Smedt et al., 2013) (see figure AS.1).

Functional imaging research has by and large supported the distributed nature of mathematic cognition postulated by Dehaene et al. (2003), although the triple code model may need updating as neuroscience research has identified not just three, but four functionally inter-related areas where mathematical processing occurs.

The ability to handle number magnitude, or number sense (Dehaene, 1999) has been found to exist in the left and right intraparietal sulci (Dehaene et al., 2003), independent of input modality, i.e. whether the representations are encoded from a digit, word or collection of objects (Trott, 2010c).

The second region, the left angular gyrus, supports number fact retrieval and digit naming. It is a region previously associated with linguistic processing (Delazer et al, 2005). Kaufmann et al. (2013) explained that the “anatomical vicinity to brain regions supporting language is not surprising upon acknowledging that in most Western cultures, arithmetic facts are acquired and retrieved phonologically” (p764).

The processing of written calculations occurs in the occipital brain regions, including the visual word form area (Price & Devlin, 2003). This area is not solely activated by written language, but responds to Arabic digits and mathematical symbols (Polk et al., 2002).

The final region is the posterior superior parietal lobule and is where visual spatial processing occurs. It is activated during tasks involving spatial and temporal awareness and is where the mental number line is actuated (Kaufmann et al., 2009). Dyscalculic students usually struggle with the formation of a mental number line, which is created in
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a logarithmic fashion, rather than linear. This is the same effect that is seen in young children, where the imagined distance between smaller numbers is exaggerated and the distance between larger numbers is minimised (Kucian et al., 2006; Van Vierson et al., 2013). A poorly formed mental number line can lead to the numerical distance effect, where the reaction time for comparing numerically close numbers is significantly increased (Dehaene et al., 1990).

Structural imaging has shown that there is less volume of grey matter present in both hemispheres of the parietal regions in dyscalculic individuals when compared to a control sample (Molko et al., 2003; Cappelletti & Price, 2013). Grey matter is the part of the brain that contains neurons and is associated with processing information.

Figure AS.1 – Location of mathematical functions of the brain (Gray, 2009)

Genetic research

There has been little genetic research into dyscalculia, but some evidence has suggested that dyscalculia, like many other specific learning differences such as dyslexia and AD(H)D, is a hereditary neurodiversity (Shalev & Von Aster, 2008). Gross-Tur et al. (1996) noted in a demographic study that 10% of parents of dyscalculic children described another family member with mathematical difficulties, whilst 45% reported another family member with a specific learning difference. Shalev et al. (2001) observed a familial prevalence of dyscalculia almost ten times greater than for the general population, whilst Ansari and Karmiloff-Smith (2002) found that dyscalculia was exceptionally common in identical twins, and significantly prevalent with fraternal twins and other siblings.
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Until recently research had shown no gender bias with dyscalculia. However recent research by Reigosa-Crespo et al. (2012) has shown that a stricter definition of dyscalculia based upon Butterworth’s (2005a) theory of numerosity and subitising does suggest a four to one dominance of dyscalculia within males. The same study also showed that by using a looser definition of dyscalculia based upon general mathematical difficulty, the gender split was even.
Appendix N – Legislation

The recognition and support of students with a specific learning difference (SpLD) has its roots in the 1995 Disability Discrimination Act (DDA), which defined disability as an individual's capability to carry out "normal day-to-day activities" (Parliament, 1995, part 1:1:1). This vague definition omitted neurodiversity, and as a result many dyslexia-related accusations of discrimination in the workplace in the late 1990s were not upheld on the grounds that the complainant was not considered disabled under the DDA (Gooding, 2000). The DDA could be considered at odds with the social model in that the process of disability identification required a medical-style intervention (Riddell et al., 2005).

The original DDA only considered the workplace and excluded the education sector. This omission was rectified when the DDA was amended by SENDA, the 2001 Special Educational Needs and Disability Act, which legislated to ensure "further provision against discrimination, on grounds of disability, in schools and other educational establishments" (Parliament, 2001, chapter 10). In SENDA, 'learning disabilities' were included under the new law, although there were no guidelines as to the severity of the neurodiversity required to qualify for legislative protection (Taylor et al., 2009).

In 2010 new legislation entitled the Equality Act came into force. This amalgamated and consolidated previous separate anti-discrimination regulations, most notably the Equal Pay Act (Parliament, 1970), Sex Discrimination Act (Parliament, 1975), Race Relations Act (Parliament, 1976) and Disability Discrimination Act (Parliament, 1995). The Equality Act was also designed to mirror existing European Union directives in the field of anti-discrimination law (Parliament, 2010). One improvement within this legislation was to clarify the inclusion of SpLDs by offering examples, such as "autistic spectrum disorders (ASD), dyslexia and dyspraxia" (Parliament, 2010). Specific issues relating to education were also addressed in a separate guideline document. The legislation covered the admission, academic and everyday service provision of HE students, although discrimination arising from disability would not be unlawful if the service provider could show that it did not realise (or could not be reasonably expected to know) that the person was disabled (Parliament, 2010). HEIs need to take reasonable steps to identify whether a student is disabled, whilst ensuring that any "enquiries do not infringe the disabled person’s privacy or dignity" (Parliament, 2010). Students have a right to non-disclosure, but HEIs need to show they have developed a pro-active culture towards inclusivity as they are legally bound (Parliament, 2001; Parliament, 2010) to make reasonable adjustments to prevent disabled students from being disadvantaged.
Appendices

Appendix O – Sample nursing and midwifery charts

![Scottish early warning system assessment form (SEWS)](image)

*Figure AO.1 – Scottish early warning system assessment form (SEWS)*
Appendices

Body Mass Index (BMI) Chart for Adults

 Axes mark numerous intermediate values

BMI values given in each cell

Figure AO.2 – Body mass index (BMI) chart 1

Axes leave gaps between values

BMI values need to be estimated from curves

Figure AO.3 – Body mass index (BMI) chart 2
### Appendix P – Code list and hierarchies

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Appendices

Appendix Q – Sample code network diagram

Network diagram for **Support**  
Key: code name (x, y)  
\[x = \text{number of code occurrences}\]  
\[y = \text{number of network connections}\]  

![Network Diagram](image-url)
### Appendix R – Sample section code matrices

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