Behavioural Fluency: An Investigation of Instructional Approaches to Build Fluency with Academic Skills and Associated Outcomes

Aoife Mc Tiernan

Dissertation submitted in partial fulfilment of the requirements for the Degree of Doctor in Philosophy in Applied Behaviour Analysis

Supervisor: Dr. Jennifer Holloway
National University of Ireland, Galway
Co-supervisor: Dr. Olive Healy
Trinity College Dublin

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Declaration and Statements

DECLARATION

This work has not been previously accepted in substance for any degree, and is not being concurrently submitted in candidature for any degree.

Signed... (candidate)

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s).

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Abstract

This thesis investigates the efficacy of instructional approaches designed to build fluency with mathematics skills, specifically, frequency-building, Precision Teaching (PT) and the Morningside Mathematics Fluency curricula. The impact of fluent performances on standardised measures of mathematical ability was examined, in addition to several critical learning outcomes associated with fluency. Analyses were further conducted to identify moderators of fluency-based instruction to inform the design and delivery of such instruction.

Frequency-building instruction was implemented with 14 participants (aged 9-11 years) in Chapter 2. A between-group design was used to evaluate the outcomes of the intervention targeting fluency with multiplication and division. Participants were matched with 14 control participants who received treatment as usual (TAU). The Experimental Group attained higher scores than the Control Group on measures of fluency with target skills and critical learning outcomes (i.e., endurance and stability) at post-testing. Increases in scores on a standardised assessment of mathematical ability were also observed for the Experimental Group only, with significant differences between groups at post-testing.

A between-group design was employed in Chapter 3 to evaluate frequency-building instruction in conjunction with PT to increase fluency with addition and subtraction. The intervention was implemented with 24 participants (aged 6-8 years) while the Control Group consisted of 18 participants, who received instruction with reading skills. Statistically significant differences between groups were found on measures of critical learning outcomes (i.e., endurance and application) at post-testing; however, no differences in scores were found on standardised measures of mathematical ability.

The findings in Chapters 2 and 3 indicated that individual differences, and the intensity at which instruction was delivered, potentially moderated the impact of the frequency-building interventions. Chapters 4 and 5 investigated the ability of individual differences and the intensity of frequency-building instruction to moderate outcomes of frequency-building mathematics skills with 71 participants (aged 6-12 years). Participant age, grade, processing speed ability and pre-intervention level of fluency with instructional materials were found to impact the ability to progress through frequency-building instruction. The findings are discussed in relation to the importance of matching fluency-based instruction to individual students' needs.

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List of Acronyms

ABA: Applied Behaviour Analysis
ADHD: Attention Deficit Hyperactivity Disorder
AET: Active Engaged Time
ANCOVA: Analysis of Covariance
BOSS: Behavioral Observation of Students in Schools
CRCT: Criterion Referenced Competency Test
DCM: Digits Correct per Minute
DEIS: Delivering Equality of Opportunity in Schools
DIBELS: Dynamic Indicators of Basic Early Literacy Skills
DPR: Detect, Practice, and Repair
EAB: Experimental Analysis of Behaviour
ET: Explicit Timing
GORT-IV The Gray Oral Reading Test, Fourth Edition
HELPS Helping Early Literacy with Practice Strategies
IH: Instructional Hierarchy
LA: Low Achiever
MLD: Mathematical Learning Disability
ORF: Oral Reading Fluency
PET: Passive Engaged Time
PSI: Processing Speed Index
PT: Precision Teaching
RTI: Response to Intervention
SCC: Standard Celeration Chart
SSRD: Single-Subject Research Design
TA: Typical Achiever
TAU: Treatment As Usual
TP: Taped Problems
WIAT-II: Wechsler Individual Achievement Test, Second Edition
WJIII: Woodcock Johnson, Third Edition

Conference Presentations and Manuscripts in Preparation

Manuscripts in Preparation

Mc Tiernan, A., Holloway, J., Healy, O., Hogan, M. (2014). An Evaluation of Frequency-Building Instruction to Increase Mathematics Skills and Associated Outcomes.

Conference Presentations

Mc Tiernan, A., Holloway, J., and Healy, O. (2013, April). Efficacy of Frequency-Building Component Mathematic Skills with Children in Mainstream Settings. Paper presented at the 7th Annual Conference of the Division of Behaviour Analysis, Ireland.

Mc Tiernan, A., Holloway, J., & Healy, O. (2014, April). Outcomes of Precision Teaching on Math and Reading Performance in Children from Disadvantaged Educational Backgrounds.

Chapter 1:

Literature Review

1.1 Behavioural Fluency

Behavioural fluency is a combination of accuracy plus speed of responding that enables competent individuals to function efficiently and effectively in their natural environments (Binder, 1996). Such fluent responding and performance is observed as “second nature”, effortless and without error, and its achievement is reliant on deliberate and well-designed practice (Johnson & Street, 2013). The concept of practicing to achieve quick and accurate performance is one which is recognised across a number of disciplines as essential to achieve proficiency and excellence. Athletes and musicians practice skills repeatedly in order to become adept in their performance while learners of a second language acknowledge that practice with proficient speakers of that language is crucial in order to attain “fluency” (Binder, Haughton & Bateman, 2002; Beverley, Hughes & Hastings, 2009). Accomplished individuals are associated with the ability to perform skills correctly with ease and fluency (Binder et al., 2002).

Within the context of Applied Behaviour Analysis (ABA), the premise of building fluent behaviours originated from the Experimental Analysis of Behaviour (EAB); specifically, experimental research evaluating free-operant conditioning. Most of the principles and methods derived from EAB, such as schedules of reinforcement, response shaping and stimulus fading, were derived from experiments in which the principle measure of the strength of a response was rate of responding (Binder, 1993; 1996) and continuous measurement of behaviour frequencies were conducted. Consequently, researchers and practitioners within the field of ABA, specifically behavioural fluency, target free operant responding as opposed to paced or controlled opportunities to respond with immediate consequences. This involves allocating a specific duration of time during which behaviours are emitted continuously. Within this context, reinforcement is contingent on increased frequencies of correct behaviours (i.e., rate of correct responding) rather than instances of correct responses alone.

Frequency monitoring as compared to percentage correct monitoring was reported to be fifty times more sensitive to environmental changes (Lindsley, 1991). Skinner later observed response frequency measures and the cumulative response recorder as among his most important contributions (Binder, 1996). The significance of using measures of frequency are further emphasised by Ferster and Skinner (1957), who describe the strength or rate of a response as the probability of the future occurrence of that response. Johnson and Street (2013) maintain that the most important element of frequency as a measure of behaviour is its ability to accurately represent the probability of future occurrences of behaviour. They further suggest that behaviours which occur at higher rates (i.e., are fluent) are functionally different from behaviours that occur at lower rates. Such high frequency behaviours are purported to occur without self-prompts, pauses or strategies designed to remember, have a different impact on the environment, are often described as habitual or reflective of individuals' tendencies and are used to predict how an individual will behave in the future (Johnson & Street, 2013).

1.2 Behavioural Fluency in Education

Despite the use of rate of responding as the primary measure of performance in EAB research, rate of responding measures were not generally employed when basic laboratory discoveries were extended into education and training (Binder, 1996). Instead, within ABA, performance was typically assessed using accuracy and percentage correct as a measure and mastery was inferred from this data (Binder, 1993). However, proponents of behavioural fluency purport that frequency measures, which provide information on the fluency with which skills can be performed, are a more useful measure of mastery in educational settings. Such measures not only assess the presence of skills in students' repertoires but also the probability that a student will engage in this skill in the future (Johnson & Street, 2013). Thus, the rate at which an academic skill can be completed correctly is deemed to determine the usefulness of that skill to the learner (White, 1986).

Mastery is conventionally defined in the context of accurate performance of a skill and percentage correct, with 100% correct on assessment representing mastery of a particular skill. This measure of accuracy alone has been widely adopted as the method of evaluation of an individual's competence across instructional settings (e.g., university assessments, assessments of reading and mathematics in primary schools and leaving certificate examinations in secondary schools). It is suggested however that percentage correct measurements omit vital information regarding level of competence (e.g., number of opportunities presented to respond and how long it has taken a learner to complete their work) and cannot distinguish between learners who are accurate but struggling and those who are fluent (Binder et al., 2002).

For such reasons, a number of early researchers and practitioners within the field of ABA did employ rate of correct responding as a measure of mastery within special education teaching environments. Their objective was to incorporate frequency measures into a wide range of classrooms to monitor students' progression through instruction and to assess true mastery of academic skills (Binder 1996; Lindsley, 1991). This was achieved by integrating brief daily timed probes of correct and incorrect academic responses into instruction (Binder, 1993). Daily timed probes involve allocating a specific time (e.g., one minute) during which free operant responses pertaining to a specific skill (e.g., writing letters) are recorded.

The number of correct and incorrect responses achieved during this time is subsequently recorded on a chart. In this way, data-based decisions can be made regarding instruction, by monitoring the rate at which responses can be emitted correctly across each additional day of instruction. If students emit high and accurate rates of responding (i.e., achieve fluent performances) as a result of instruction, the instructional approach being implemented is determined to be effective. However, if increases in the same are not demonstrated, changes to the instructional approach are applied.

In order to achieve such fluent performances, fluency-based instruction can be incorporated so that high rates of correct responding are attained. Given that the definition of fluency includes *both* accuracy and speed of responding, it follows that once students demonstrate 100% accuracy (i.e., the conventional measure of mastery), further instruction is conducted in order to achieve true mastery (i.e., accuracy and high rates of responding) with academic skills. This is achieved with additional practice, taking into consideration the time which is necessary to complete specific academic tasks. As with the daily timed probes, this usually involves allocating a specific time during which students are instructed to emit as many correct responses as possible *or* to complete a task. In addition, students are requested to continue with such timed practice until a sufficient rate of correct responding has been achieved and the skill is deemed to be mastered.

Although very little of the early research was recorded in the professional literature (Lindsley, 1990), findings are anecdotally reported to have demonstrated the importance of achieving fluent performances to attain proficiency within an academic domain. These early findings suggest that in order to progress proficiently through educational curricula, minimum rates of correct responding should be achieved with target skills and that this applies to a broad range of curriculum areas (Binder, 1993; 1996; Lindsley, 1990). Haughton (1980) emphasised that the mere presence or accuracy of a response class in the repertoire of a learner is not sufficient to ensure progress through a curriculum sequence which depends on that response class as a pre-requisite. The achievement of fluency with pre-requisite response classes is purported to be essential in order to attain overall proficiency with educational curricula within each academic domain (Binder, 1996). More recent research, investigating the relationship between fluency and overall ability within an academic domain, report findings with significant implications for the incorporation of fluency-based instruction within educational settings (Begeny, Ross, Greene, Mitchell & Whitehouse, 2012; Carr & Alexeev 2011; Carr, Steiner, Kyser and Biddlecomb, 2008; Hughes, Beverley & Whitehead (2007).

1.3 Fluency and Academic Ability

Research investigating the link between fluent performances of academic skills and general academic ability, has demonstrated significant findings, predominantly in the reading and mathematics domains. Reading fluency has been determined as one of the most essential components of proficient reading (Calhoon & Petscher, 2013; Silber & Martens, 2010). Oral reading fluency has been described as the rate at which readers accurately recognise individual words within a connected text (Burns et al., 2011) and consists of speed, accuracy and proper expression or prosody (Begeny et al., 2009; Heikkilä et al., 2013; Schwanenflugel, Westmoreland & Benjamin, 2013; Silber & Martens, 2010). It is measured by recording the number of words read aloud correctly and incorrectly per minute (Kubina & Starlin, 2003). Numerous studies have found significant correlations between proficiency in oral reading fluency and reading comprehension (Basaran, 2013; Burns, Dean &

Foley, 2004; Burns et al., 2011; Fuchs, Fuchs & Hosp, 2001) indicating the benefits of achieving fluent performances in order to become proficient readers.

Begeny et al. (2012) investigated a strategy called Helping Early Literacy with Practice Strategies (HELPS) which integrates instructional strategies to increase oral reading fluency. The strategies used to increase oral reading included; repeated reading, modelling, phrase-drill error correction, verbal cueing for students to read with fluency, goal setting, performance feedback and a reinforcement system. Participants were 21 second-grade students with an average age of 7.76 years. Thirteen participants were randomly selected to receive the HELPS program while eight participants served as a control group (only received instruction with the core reading curriculum). The Gray Oral Reading Test, Fourth Edition (GORT-IV; Wiederholt & Bryant, 2001) was used to evaluate the effects of intervention. This is a standardised norm-referenced assessment providing a composite score of overall reading ability incorporating tests of reading accuracy, fluency and comprehension. The intervention was implemented 2-3 times per week for five months. Using Mann-Whitney U tests, mean GORT-IV scores at post-tests were compared between groups. Results showed that participants who received the HELPS had significantly higher scores than control participants on measures of reading fluency and comprehension at post-testing.

Hughes et al. (2007) targeted rate of reading common English words with participants between the ages of 11 and 12 years. Timed practice was implemented to increase accurate and fluent word reading with five participants whose reading ages were significantly below their average peers. A treatment as usual (TAU) group, consisting of two participants, was allocated the same amount of time to practice reading but did not build fluency. Instead, they were told to choose a book and read it with the teaching assistant. Increases in fluency with target words were found for all five participants over the 10-week intervention. The Group Reading Test II (GRT II; NFER-Nelson, 2000), a standardised norm-referenced assessment of decoding and reading comprehension, was administered with all participants pre- and post-intervention. The mean reading age of the participants who received intervention increased by three months while the mean reading age for the two control participants decreased by one month.

With respect to mathematics, research studies investigating fluency-based instruction with mathematics skills have largely focused on the efficacy of such instruction to increase rate of correct responding. In a meta-analysis examining interventions targeting both acquisition and fluency with computation skills in mathematics, Codding, Hilt-Panahon, Panahon and Benson (2009) note the paucity of research examining generalisation effects associated with fluency-based instruction. Dependent variables within the literature consist mostly of accuracy and/or rate of responding with target skills with a lack of research examining generalised outcomes on standardised measures of mathematical ability.

However, a link between fluent performances of mathematics skills and overall mathematical ability has been reported in the literature. In a sample of 241 students in the second grade, Carr et al. (2008) assessed fluency with single-digit arithmetic problems (i.e., addition and subtraction problems) and mathematical ability. Mathematical ability was assessed using a Criterion Referenced Competency Test (CRCT). While this assessment was not normed or standardised, it measured a broad range of skills related to computation and estimation, geometry, patterns/relations, algebra, problem solving and number sense. Regression analyses demonstrated that scores on fluency measures significantly predicted mathematical ability as assessed using the CRCT.

In a follow up study, Carr and Alexeev (2011) examined growth trajectories in mathematical ability with 240 participants who had taken part in the previous study. The CRCT was administered to all participants again at the end of fourth grade. While the findings in the 2008 study demonstrated that fluency, accuracy and gender all influenced mathematical ability, the results of the 2011 study found that fluency had the most significant impact on growth in mathematical ability.

Given that such a significant link has been demonstrated between fluency and general mathematical ability, research examining fluency-based instruction with mathematics skills should incorporate standardised measures of ability to ascertain if they are impacted as a result of intervention. Further, investigations of the impact of fluency-based instruction on standardised measures of ability should include large sample sizes to facilitate rigorous analyses of between-group differences.

1.4 Critical Outcomes Associated with Behavioural Fluency

Early findings investigating behavioural fluency in educational settings, and more recent emerging research in the area, suggest that additional outcomes, critical to learning and education, are associated with fluent performances of academic skills. Fluent skills are purported to be retained and performed on demand long after they have been learned, more readily applied in real-world contexts other than that in which they were learned and performances of such skills are sustained for extended time periods amidst distractions to meet real-world requirements (Binder, 1996; Binder et al, 2002; Johnson & Street, 2013). Behavioural fluency theorists propose that when a student achieves a fluent performance, such critical learning outcomes will occur (Binder, 1996; Brady & Kubina, 2010). Haughton (1980) first identified critical outcomes associated with fluency as retention, endurance and application (REA-PS; Retention, Endurance, Application – Performance Standards).

1.4.1 Endurance

Endurance has been defined as the ability to engage in a skill for prolonged periods without fatiguing (Fabrizio & Moors, 2003) or the ability to meet real-world requirements for the duration that the skill is required to be performed (Johnson & Street, 2013). Binder, Haughton and Van Eyk (1990) equate endurance to the ability to maintain “attention” to a task and suggests using the definitions of endurance to describe “attention span” rather than attempting to explain it through complex cognitive processes. It is suggested that individuals typically lack the ability to maintain a “steady” performance for extended durations of time until a minimum level of speed and accuracy with relevant skills is achieved (Binder et al., 1990). Further, extended performances of skills which are performed at low rates often produce increased error rates and negative behaviours (Binder et al., 1990).

Endurance is purported to improve when the performed skills are fluent; however, few research studies have investigated the impact of fluent performances on participants’ ability to endure. Brady and Kubina (2010) investigated fluency-based instruction with mathematics skills in relation to ability to endure with three participants with a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). The mathematics skill targeted for fluency-based instruction was writing correct answers to multiplication problems. Endurance was assessed by conducting 1-minute timings with each participant, during which the number of correct digits written per minute was recorded. Building fluency using 20 second practice timings (i.e., 20 seconds allocated during which students are instructed to emit as many correct responses as possible) and 10 second corrective feedback sessions was found to increase participants' ability to endure during the extended 1-minute timing.

McDowell and Keenan (2001) examined the effects of teaching letter sounds fluently to increase rate of correct responding and endurance with a 9-year-old boy with ADHD. Endurance was measured as time spent on-task as opposed to number of correct responses achieved per minute. On-task behaviour was described as the percentage of each session spent on-task as observed by the experimenter. During baseline sessions, the participant's on-task behaviour was observed to be between 50% and 60% with an increase to 100% during the final four sessions of the fluency intervention.

1.4.2 Stability

Stability has been described as the ability to maintain performance in the presence of distracting stimuli (Johnson & Layng, 1992; RESA-PS; Retention, Endurance, Stability and Application – Performance Standards). Johnson and Street (2013) describe stability as the ability to continue to perform a skill amidst distractions and argue that academic tasks quite often require this kind of stability in the face of distraction. No research to date has experimentally evaluated the assertion that achieving fluent performances improves a student's ability to perform in the presence of environmental distractions.

1.4.3 Application

Application has been defined as the ability to use a skill in a real-world context in which it is required, differing from the typical classroom task (Johnson & Street, 2013) or the extension of a skill to untaught examples (Fabrizio & Moors, 2003). Fabrizio and Moors (2003) assert that this is a major goal of any instruction so that skills are useful to individuals in differing situations other than those in which they were taught. The ability to apply skills in differing situations is suggested to improve when those skills can be performed fluently. Kubina and Yurich (2012) describe application as the ability to apply one or more element behaviours or pre-requisite skills to more complex behaviours or skills once a specific frequency with those skills is achieved (e.g., the ability to recognise or read letters at a high frequency will result in an improvement in applying this skill to decoding full words). Similar to endurance and stability, there is a paucity of research which experimentally demonstrates the occurrence of this outcome when fluent performances are attained.

Chiesa and Robertson (2000) implemented a 12-week fluency-based intervention with five participants in primary school (9-10 years of age) who were unable to keep pace with their peers on the mainstream mathematics curriculum. The ability to apply skills was evaluated using pre- and post-intervention measures with 25 participants on a complex mathematics skill requiring the use of pre-requisite skills taught during intervention. This complex skill was the division of two-digit numbers by one digit for numbers up to and including five and was taught to all 25 participants prior to the intervention implementation. Pre-requisite skills were identified and taught to fluency criteria with the five experimental participants. The authors describe multiplication as the inverse of division and so identified multiplication tables, beginning with multiplication by one and up to multiplication by five, as pre-requisites which could be applied to the more complex skill of division of two-digits by one. The remaining 20 participants represented a TAU control group. Post-tests demonstrated that the five participants who had received fluency-based instruction with multiplication tables achieved a higher rate of correct responding while performing division problems than all but one of the control participants. Mean scores on this measure increased from one to 13.2 for the five experimental participants from pre- to post-testing, while a smaller increase from 3.7 to 4.2 was found with the control participants. The findings indicated that fluency-based instruction with multiplication skills improved participants' ability to apply those skills to more complex problems.

1.4.4 Retention

Retention has been defined as performance following a period of time without practice or opportunity for reinforcement (Fabrizio & Moors, 2003). When students attain higher rates of correct responding with a skill, they are said to be able to retain the ability to perform that skill at a similar rate, on demand, in the future without further instruction. A number of studies targeting an increase in fluency with academic skills incorporate retention "checks" (Codding, Archer & Connell, 2010; Hawkins et al., 2009; Miller et al., 2011; Mong & Mong, 2012), which involve stopping timed practice for a pre-determined length of time (e.g., 1-6 months) followed by timed probes to measure rate of correct responding. However, few studies have focused on empirical evaluations of this outcome.

Each of the critical outcomes discussed, namely endurance, stability, application and retention, are essential aspects to learning and education. Academic assignments frequently require performance over extended durations of time and in the presence of distracting stimuli (e.g., engaging in a lesson within a classroom setting). The ability to apply skills learned within educational programmes and settings is the goal of any instruction so that skills are useful and valuable to students. Related to this, the retention of skills is also an important goal so that skills are useful long after instruction has been completed.

Although the occurrence of each outcome has been associated with the attainment of fluent performances with target academic skills (Binder, 1993; 1996; Johnson & Street, 2013), few research studies have demonstrated a functional relationship between fluency and each outcome. Promising findings have been reported in the literature to date so that further investigation should yield significant implications for instructional practices in educational settings. Weiss et al., (2010) suggest that each critical outcome seems achievable in theory; however, more rigorous, empirically-based research is needed to validate them. In addition to, and as a result of, the lack of research evaluating each outcome, some further issues need to be addressed within future investigations. Specifically, research is necessary regarding the measurement of each outcome *and* the exact level of performance which is required to attain such outcomes for differing academic skills and individual students.

1.4.5 The Measurement of Critical Learning Outcomes

Definitions of the critical outcomes in the literature, while describing what each involve, are not conducive to precise and consistent measurement across research studies investigating their occurrence. For example, endurance is defined as the ability to engage in a skill for prolonged periods of time without fatiguing (Fabrizio & Moors, 2003) or the ability to meet real-world requirements for the duration that the skill is required to be performed (Johnson & Street, 2013). Such definitions do not represent operational definitions allowing precise and consistent measurement of this outcome.

McDowell and Keenan (2001) investigated endurance by evaluating the percentage of fluency-building sessions for which participants were observed as on-task. Brady and Kubina (2010) investigated the same outcome by measuring the ability to increase rate of correct responding during increased durations of responding. Further, Weiss et al. (2010) suggest that endurance can be tested by increasing the length of time for which the learner must practice a skill without fatiguing (i.e., increase the length of timing which is used during fluency-based instruction) while keeping all other components of timed practice constant (including materials and level of distractibility).

Application is defined as the ability to use a skill in a context which is different from the typical classroom task (Johnson & Street, 2013). It has also been defined as the extension of a skill to untaught examples (Fabrizio & Moors, 2003) and it has been suggested that it should be assessed by changing the instructional materials to novel, untrained materials, for example, the use of different pictures, objects or texts, or rephrasing questions from how they were taught during instruction (Weiss et al., 2010). Kubina and Yurich (2012) describe application as occurring when fluency is attained with one or more pre-requisite skills and as a result, they are more easily applied to more complex behaviours. Further, Chiesa and Robertson (2000) demonstrated positive outcomes in the ability to apply multiplication tables to the more complex, but related, skill of division. Similar to definitions of endurance, application is not defined consistently throughout the literature. One consistent, precise and measurable definition of application has not been determined so that difficulties arise in relation to the measurement of this outcome across research studies.

Stability is described as the ability to continue to perform a skill in the presence of distracting stimuli (Johnson & Layng, 1992). Despite the importance of such a skill within educational settings, this outcome features very rarely in the behavioural fluency literature. However, it is suggested that stability be measured by changing the environment to ensure the learner can engage in the skill in the presence of distracting stimuli (Weiss et al., 2010). Such distractions are further described as possibly including sounds, activities, items and/or people that are not in place during instruction and a key element of testing for stability is that it should occurring the presence of distracting stimuli.

Further investigation focusing on critical outcomes is necessary, not only to demonstrate their occurrence as a result of attaining fluent performances, but also to more precisely define and measure each. Such learning outcomes are essential aspects of learning and for this reason warrant a great deal of attention in the literature. Yet, current definitions of critical learning outcomes create difficulties for researchers interested in investigating functional relationships between their occurrence and fluent performances. Further research should contribute to more precisely defining and measuring such outcomes so a better understanding of each is achieved and consistent measurements are employed across research studies.

1.4.6 Determining Performance Criteria: Fluency Aims

Procedures and instructional approaches are implemented with the goal of increasing rate of correct responding and achieving fluent performances with academic skills. However, gaps in the research exist regarding the determination of performance criteria which represent a fluent performance. In other words, what frequency of responding should a student achieve in order to deem their performance “fluent”. Binder (1996) outlines the empirical definition of fluency as related to its measured effects and suggests that, when a combination of speed plus accuracy of performance optimises critical learning outcomes, this is the level that can be defined as a fluent performance. As such, a performance can be described as fluent once a student can demonstrate endurance, stability, application and retention. Based on this empirical definition of fluency, a proportion of research investigating fluency-based instruction incorporates “checks” of critical learning outcomes (Foley & Fabrizio, 2007; Hughes et al., 2007). Such “checks” are conducted after fluency-based instruction has been implemented and each outcome is generally tested in the manner outlined by Weiss et al. (2010). The reliance on “checks” within such studies, to determine an appropriate level of fluency has been achieved, further emphasises the need for empirical examinations of each outcome since so few studies have demonstrated a functional relationship between fluency and each outcome to date.

However, the predominant method by which performance criteria are determined is with the development of fluency aims. Fluency aims are determined prior to implementing fluency-based intervention and dictate the quantity of instances of performance of a skill that students are expected to complete within a specified amount of time (i.e., the rate at which the skill should be performed) in order for a skill to be deemed “fluent”. For example, learners must read 200-220 words per minute, write 60-80 letters per minute or write 50-60 answers to mathematics problems per minute. Once students achieve their fluency aims, they are purported to have achieved a sufficient level of fluency to improve performances on critical outcomes.

Binder (1996) suggests that the determination of performance standards or fluency aims for so many response classes, which are sufficient to effect improvement in critical outcomes, represents the necessity for a vast quantity of research. Alternatively, it is suggested that educators should evaluate previous research as a guideline for setting individual fluency aims or sample the skill with a group of competent learners, thereby identifying the average performance of this group as the aim (Binder, 1996; Kubina & Yurich, 2012). In line with this, Kubina and Yurich (2012) have published a number of fluency aims gathered from descriptive and developmental research and observational data which are suggested to serve as a guideline for setting fluency aims across a wide range of skills (some of these aims include: read 100-120 correct letter sounds in one minute, write 90+ correct letters in one minute, write 120-160 correct numbers between 0-9 in one minute, say 20+ words which are opposites in one minute). The authors caution that such fluency aims should not be considered unchangeable and that a better understanding will emerge with regards to the performance criteria necessary to produce critical outcomes with future research.

Explicit fluency aims facilitate interventions focused on achieving sufficient levels of fluency with academic skills (Binder et al., 2002) and as such are an essential part of fluency-based instruction. Currently, the recommended method by which such aims are determined is to sample target skills with groups of fluent learners. However, fluency aims determined using this method may not be transferrable to all students and researchers caution that they should not be considered unchangeable. A great deal of research is necessary to inform best practices for selecting appropriate fluency aims, for individual students across a number of academic skills, and to determine methods by which this process may be facilitated.

1.4.7 Generativity

More recently, fluent performances of academic skills have been purported to impact generativity. This is defined as the emergence of complex behavioural repertoires without explicit instruction (Johnson & Street, 2004; MESAG-PS; Maintenance, Endurance, Stability, Application and Generativity – Performance

Standards). Although similar in principle to application, generativity extends beyond this, describing situations in which students can respond to novel situations by blending and combining already mastered skills without prior training (Johnson & Street, 2013). Generativity is said to occur as a result of building fluency within the context of generative instruction (Johnson & Street, 2013). Generative instruction involves the combination of component-composite analysis of behaviour, cumulative instruction with component skills and procedures that increase fluency with component skills (Johnson & Layng, 1994).

1.4.7.1 Component-Composite Analysis

Equally as important as the attainment of fluent performances with academic skills, is the identification of skills which are best targeted for fluency-based instruction. Within most areas of education basic pre-requisite skills can be identified which all individuals must acquire in order to progress through a curriculum. A curriculum develops such pre-requisite skills into more complex behavioural repertoires by moving systemically through a sequenced hierarchy of interlocking goals. For example, within the domain of mathematics, initially basic skills, such as pointing, naming, counting, grouping, adding and subtracting, are taught to early learners. These basic skills are foundational to more complex mathematics skills such as multiplication, long division, fractions, trigonometry, geometry, calculus, and matrices. When pre-requisite skills are not fluent, they can prevent the development of overall fluent performance in an academic domain (Binder, 1993).

Generative instruction targets key pre-requisite skills for instruction in order to facilitate effective teaching and learning (Johnson & Layng, 1992). Component-composite analysis is inherent in this type of instruction. This involves breaking down each teaching goal into sets of tool skills, component skills and composite skills (Johnson & Street, 2013). Tool skills are the minimal responses that are necessary to perform a number of more complex skills (e.g., holding a pencil, making marks on a page with a pencil). Component skills are described as 'second-level building blocks' which are comprised of a series of interlocking tool skills (Johnson & Street, 2013). Component skills are also considered as pre-requisites to engaging in composite behaviours (e.g., writing numbers, writing letters). Finally, composite skills are the higher level performances that represent mastery of a content area and are composed of combinations of component skills; writing answers to mathematics problems or writing a story would be considered an example of this type of skill (Johnson & Street, 2013). Table 1.1 shows examples of related tool, component and composite academic skills.

Skill level	Description	Examples of the relationship between tool, component and composite skills	
Tool Skill	Minimal response sets that underpin all other target skills	Pinching	Writing numbers
Component Skill	Second level building blocks –depend on one or more tool skills	Holding a pencil Making marks	Single-digit math problems
Composite Skill	Higher-level performances; combinations and blends of component repertories	Writing numbers	Basic computational algorithms

Table 1.1 Description of tool, component and composite skills (Johnson & Street, 2013)

Most academic tasks involve the performance of several different skills at once so that any task can be described as a composite and broken down into its pre-requisite series of component skills. In order to strengthen a composite skill, analyses of its pre-requisite tool and component skills are essential (Chiesa &

Robertson, 2000). Within a generative instruction approach to teaching, when such skills are identified they are taught to a fluency criterion of mastery. Binder (1996) describes a constraint on the ability of reinforcement alone to increase proficiency with composite skills when component skills are not fluent. Performances of component skills at low frequencies impose ceilings on the ability to perform composite skills proficiently. For this reason, he argues that building fluency with component skills should be a focus of instruction in all educational settings.

Conversely, in general education settings, students' mastery of skills taught at each level of a curriculum are typically assessed using a measure of accuracy only. Proponents of behavioural fluency assert that accurate performances of such skills are not sufficient to progress proficiently through a curriculum. McDowell and Keenan (2001; 2002) evaluated the relationship between levels of fluency with component academic skills and performance of composite skills within two separate studies. In the 2001 study, seven students with difficulties performing composite academic tasks (i.e., writing answers to multiplication problems and addition problems and identifying words) participated. Each composite task was broken down into two or three component tasks (e.g., for identifying words, the component tasks were identifying letter and syllable sounds) and level of fluency for each of the related component skills was assessed. All participants were "dysfluent" (i.e., did not perform the skills fluently) in 2 or 3 component skills of the composite task they experienced difficulty performing. Assessment of component skills produced relatively accurate performance suggesting that accurate responding alone was not enough to facilitate acquisition of composite tasks.

McDowell and Keenan (2002) evaluated the effectiveness of teaching component skills as compared to a composite skill to fluent performances with seven students with mild learning difficulties. One group (n = 4) were taught a component skill and rate of correct responding on a related second component skill and composite skill were assessed. The second group (n = 3) were taught a composite task and rate of correct responding on the component skills were evaluated. Results showed that the first group made better progress with all tasks (component and composite) suggesting the importance of teaching component skills fluently to facilitate the acquisition of more complex tasks.

Johnson and Street (2013) explain that when component skills are taught fluently, educational requirements or opportunities for reinforcement can easily recruit those skills to form novel re-combinations of relevant skills that meet the new requirement. As such, the critical outcome of generativity occurs. As a result of this outcome, students have been observed to make “curriculum leaps” in that component and composite skills within cumulative curricula emerge with little or no instruction (Johnson & Street, 2013). The ability to make such leaps facilitates efficient and independent learning.

Based on the generative instruction approach, specific curricula have been developed to teach skills across a number of academic domains. These curricula have been designed to target key component skills and facilitate cumulative fluency-based instruction. Since the combination of component-composite analysis, cumulative instruction and building fluency with component skills is suggested as the most effective and efficient method of instruction (Johnson & Layng, 1994; Johnson & Street, 2013), further research is necessary to empirically validate their use and investigate associated outcomes.

1.5 Fluency in the Mathematics Domain

Mathematics is an important core component of the educational curriculum. Competency in basic mathematics is not only necessary for completing related classwork but is also essential to everyday life. Geary, Hoard, Nugent and Bailey (2012) equate the importance of mathematical knowledge with that of basic literacy and emphasise its importance for independent functioning in society. Expertise in this area facilitates advancement in numerous other fields including business, medicine, engineering, and how individuals later perform mathematically also impacts labour quality and national growth (Lin & Kubina, 2005).

Poncy, Fontenelle and Skinner (2013) report that students in the United States (US) struggle with basic mathematics skills with only 40% of fourth graders performing at, or above, the proficient level on assessment. Irish students' performance in mathematics was statistically significantly below the OECD average in the Program for International Assessment (PISA; OECD, 2009) with students from the US similarly performing below average. Since 2009, there has been a relative improvement in the performance of Irish students to just above the OECD average (PISA; OECD, 2012) while students in the US continued to perform below average.

Since mathematics is a pivotal academic domain for future performances across many academic and applied skills, reported low performances have prompted investigations into causal factors. Further, the need for empirically validated interventions to increase proficiency with mathematics skills has been noted in the literature (Codding et al., 2009; Poncy et al., 2013). Behavioural fluency research has identified factors which contribute to low performances in the mathematics domain and added to the literature seeking to develop effective instructional practices in mathematics. Such research has identified a link between fluent performances of component mathematics skills and overall mathematical ability (Carr & Alexeev, 2011; Carr et al., 2008).

Consistent with the behavioural fluency and generative instruction literature, attaining accuracy with key pre-requisite or component mathematics skills is considered insufficient to achieve proficiency within this domain or progress through a mathematics curriculum. Specifically, Binder (1993) purports that when component computational facts are accurate but not fluent, students may not have the ability to learn from demonstrations of complex problem-solving. In the absence of fluent discriminations between examples and non-examples of a concept, students may not have the ability to use that concept as part of a more complex logical or rule-application sequence (Binder, 1993).

Others suggest that slow but accurate performances of mathematics skills can result in an inability to complete assigned mathematics tasks within set time limits with the consequence of receiving no contingent reinforcement, more delayed reinforcement or less frequent reinforcement (Bliss et al., 2010; Logan & Skinner, 1998; Skinner, 2002). The high level of response effort and low level of reinforcement associated with dysfluent mathematics skills decreases the probability that learners will engage in mathematics tasks and therefore are at risk of falling farther behind in mathematics development (Billington et al., 2004; Skinner et al., 2005; Bliss et al., 2010). Considering the findings that fluent performances of mathematics skills play such a significant role in overall mathematical ability, research is necessary to identify and evaluate the most effective and efficient methods of instruction designed to build fluency within this domain.

1.5.1 Building Fluent Performances with Mathematics Skills

Kubina and Yurich (2012) suggest that without explicitly working towards behavioural fluency, the probability that a student will become fluent is left to chance. However, developing automaticity with mathematics skills can be challenging (Miller et al., 2011). Emerging research investigating fluency-based instruction has demonstrated positive outcomes to date.

In the meta- analysis conducted by Codding et al. (2009), specific mathematics interventions, implemented with students identified as needing additional support with mathematics, were examined in relation to effectiveness of each and their ability to meet evidence-based criteria. Thirty-seven studies met inclusion criteria for the meta-analysis. Interventions were conducted across a total sample of 914 participants with a mean age of 11.06 (range: 7 – 17). Effect sizes for nine fluency-based interventions were reported in relation to their impact on rate of correct responding with targeted mathematics skills. The nine interventions included: Goal Setting (n = 3 studies), Flash Cards (n = 1 study), Count-Bys (n = 1 study), Explicit Timing (n = 1 study), Self-Instruction (n = 9 studies), Peer Tutoring (n = 8 studies), Cover-Copy-Compare (n = 6 studies), Taped Problems (n = 3 studies) and Incremental Rehearsal (n = 1 study). Table 1.2 provides a brief description of each type of instruction implemented to build fluency with target mathematics skill, as outlined by Codding et al. (2009).

Intervention	Description	Intervention	Description
Goal Setting	Students either self-set goals or are assigned goals. Goal Setting is used during drill practice and contingent reinforcement is used.	Cover-Copy-Compare	(a) look at the math problem with the answer, (b) cover the problem with the answer, (c) record the problem and the answer, (d) uncover the problem with the answer, and (e) compare the answer
Flash Cards	Students are presented with flash cards including cards that can be rapidly answered and cards answered incorrectly at baseline.	Taped Problems	A tape recording is used that corresponds with problems on a worksheet. Problem is played using recording and then a time delay. Student writes down the answer during the time delay, before the answer is provided on the recording.
Count-Bys	Teacher models how to compute multiplication facts by counting by (i.e., 3, 6, 9). Students repeat this counting scheme at a rate of one count per second.	Incremental Rehearsal.	(a) Examiner identifies known and unknown multiplication facts, (b) examiner presents first unknown fact with the answer and students repeat the fact with the answer, and (c) each unknown fact is rehearsed nine times by folding the unknown fact in with known facts.
Peer Tutoring	Students are paired and taught specific techniques for acting as instructional partners, who then work together to practice skills.	Self-Instruction	(a) Students observe teacher solving problem using self-instructions, (b) student performs task while teacher provides self-instructions, (c) student solves problem using verbal prompts with teacher's support, (d) student independently uses verbal prompts, and (e) student uses verbal prompts silently and solves the problem.
Explicit Timing	Students complete as many math problems as possible during a 1-minute interval.		

Table 1.2 Brief descriptions of fluency-based mathematics interventions as outlined by Codding et al. (2009)

Results of the meta-analysis demonstrated moderate to large effect sizes for the nine interventions to increase rate of correct responding. Each intervention was purported to be relatively easy to implement with little time, resources or training necessary. Such findings are promising in relation to the ability of specific interventions to increase fluency with mathematics skills; however, Codding et al. (2009) emphasise that most of the interventions failed to meet criteria for evidence-based practice. Interventions failed to meet criteria as a result of the limited number of studies evaluating each and the use of Single-Subject Research Design (SSRD).

SSRD's were used to evaluate interventions in 68% of the studies with the most common being multiple-baseline designs. For such research designs, it is recommended that before an intervention is deemed evidence-based practice, there must be a minimum of five published peer reviewed studies (that meet methodological criteria) with at least 20 participants across those studies (Horner et al., 2005). Codding et al. (2009) note that there were less than five studies conducted to evaluate most of the interventions and that a body of evidence has not yet been established for most interventions. They further suggest that continued research is essential to establish support for effective interventions to increase fluency with mathematics skills.

1.5.2 Frequency-Building

Kubina and Yurich (2012) describe frequency-building as the timed repetition of selected behaviour followed by performance feedback. The authors suggest that this procedure has been demonstrated as a promising approach to promoting fluency and should be incorporated in all areas of education. Timed repetition of skills or "frequency-building" can be incorporated into mathematics instruction to increase rate of correct responding with component mathematics skills.

Often within behavioural fluency research and practices, Explicit Timing (ET) is used to allow timed practice of component skills and achieve fluent performances. ET involves the presentation of a task and a specific amount of time allocated to complete it (Gross et al., 2013). Timings, which are usually one minute in duration, are conducted during which students complete as many repetitions of the target skills as they can before the timing ends. Within the context of frequency-building and ET, rate of correct responding is evaluated to determine mastery as opposed to correct responding alone and is recorded as a count of behaviour over a time unit (Kubina & Yurich, 2012).

Implementation of ET has demonstrated positive outcomes in previous research investigating its ability to build fluency with mathematic skills. Hartnedy, Mozzoni and Fahoum (2005) used a multiple-baseline design across two participants to evaluate the effectiveness of frequency-building with identifying numbers and answering single-digit multiplication facts using ET and performance feedback. Baseline measures consisted of 1-minute timed probes during which participants performed the target skills. Identifying numbers and answering multiplication facts were practiced (i.e., performed repeatedly) during 1-minute timings to build fluency with each skill. Participants received reinforcement in the form of stickers if they could improve their rate of correct responding from their previous timings. Results demonstrated a noted increase in the rate of correct responding and a decreased rate of errors across participants.

Poncy, Duhon, Lee and Key (2010) used frequency-building (i.e., ET and performance feedback) to increase fluency with 12 addition facts. A multiple-baseline design across three participants in fourth grade was used to evaluate the frequency-building intervention. Intervention was conducted in a one-to-one setting and participants were given 4-minute timings to complete as many addition problems as they could within that time. Positive reinforcement was delivered contingent on increasing rate of correct responding relative to the previous intervention session conducted. The intervention was successful across the three participants to increase rate of correct responding with targeted addition skills.

ET can also be used in conjunction with curricula or other instructional approaches. "Detect, Practice and Repair" (DPR) is an instructional approach for building fluency with mathematics skill which incorporates ET. DPR consists of three phases. The first phase involves timed probes of mathematics problems to detect those with which participants cannot perform fluently. The second phase consists of untimed practice with problems identified in the first phase, using correction sheets. The third phase of DPR is an ET procedure during which participants complete as many of the detected problems, within a larger pool of problems, as they can and rate of correct responding is recorded.

Poncy et al., (2013) used a multiple-baseline across sets of mathematics problems with 11 fourth grade participants to evaluate the effectiveness of DPR intervention to increase fluency with addition problems. DPR was found to be effective to increase fluency for all 11 participants. Axtell, McCallum, Bell and Poncy (2009) investigated DPR with 23 participants between the ages of 12 and 15 years. Pre- and post-test scores of fluency with division problems were compared to scores obtained by a control group who received a reading intervention (n = 13). Participants who were exposed to DPR demonstrated higher adjusted mean fluency scores at post-testing than the control participants.

Gross et al. (2013) investigated the effects of ET on subtraction fluency with 47 first grade participants comparing three variations of ET. The dependent variable was subtraction from 0 – 10 fluency on pre- and post-test probes. Participants were randomly assigned to one of the three interventions with between 15 and 17 in each group. Variations of the ET intervention involved differing methods of goal setting (i.e., the researcher set goals, the participants selected their own goals, or the researcher selected goals and used graphs to represent each goal to participants). Each group demonstrated an increase in fluency using ET with goal setting. Repeated-measures analysis of variance was used to determine differences between groups on subtraction fluency growth. Participants who selected their own goals demonstrated larger increases in fluency than those in the researcher selected goal group.

Consistent with the suggestion that frequency-building is a promising approach to promoting fluency (Kubina & Yurich, 2012); positive outcomes have been demonstrated in relation to its ability to increase fluent performances of mathematics skills. However, the limitations outlined by Codding et al. (2009) are pertinent to evaluating the support for such instruction in the literature. A limited number of studies have been conducted to demonstrate its efficacy and SSRD’s are the predominant experimental design used to do so. Continued research is necessary to replicate the current research findings and to employ experimental designs to evaluate the efficacy of frequency-building interventions across a larger number and range of participants.

1.5.3 Precision Teaching

When early behavioural fluency researchers and practitioners extended rate of correct responding as a measure of academic performance into classrooms, they used Precision Teaching (PT) methods to evaluate daily timed probes which they had incorporated into instruction (Binder, 1993; 1996; Lindsley, 1991). Lindsley (1971), the founder of PT, defined it as the "daily recording of the frequencies of different classroom performances on a standard chart". Such monitoring of behavioural frequencies facilitated data-based decisions regarding instruction. More recently, PT has been described as a system for precisely defining, measuring and facilitating the subsequent analysis, interpretation and decision making behaviour (Kubina & Yurich, 2012).

Hughes et al. (2007) note that although PT does promote certain practices not commonly used in classrooms (e.g., daily timed practice and frequency-building, daily measurement of performance and data-based decisions), it is not a method of instruction for building fluency; rather it is a general approach that determines whether an instructional method is achieving its aims. PT does not specify how or what to teach, it is used to evaluate the effectiveness of certain teaching strategies (Chapman, Ewing & Mozzini, 2005). For this reason it is quite often used in conjunction with frequency-building interventions to monitor rates of correct responding and evaluate the effectiveness of instructional approaches implemented to increase fluent performances.

Four guiding principles exist in PT which defines in depth the core features that should be consistent across all applications. These principles are (1) the learner knows best, (2) focus on observable behaviour, (3) use of frequency as a universal measure of behaviour, and (4) displaying data on a Standard Celeration Chart (Kubina & Yurich, 2012; White, 1986). The first principle refers to the assumption that behaviour is lawful and responds predictably to changes in environmental variables (Kubina & Yurich, 2012). PT is implemented with reference to data-based decisions on each instructional programme. The second principle, the necessity to focus on observable behaviour, is related in that it also affords objective measurement. A reliable and objective measurement system allows teachers to evaluate the effects of their instructional programme on learners' performance (Kubina & Yurich, 2012) and to make changes to that program where necessary.

Since a measure of frequency of behaviour has been shown to be more sensitive to environmental variables than traditional percentage correct measures (Lindsley, 1992), this is the unit of measurement that has been adopted by precision teachers to evaluate learning outcomes. Frequency is a direct measurement of behaviour which provides counts of individual instances of behaviour during specific observation periods (Kubina & Yurich, 2012) and its use is the third guiding principle of PT.

The final principle of PT is that data is displayed using a Standard Celeration Chart (SCC). The SCC allows observation of frequencies of individuals' performance but also the growth of learning across time (Calkin, 2005). Data-based decisions are made by examining a learner's performance on the SCC which can result in subsequent changes to the learning environment to improve learners' performance (Kubina & Yurich, 2012). Precision teachers have developed formal decision making guidelines to permit precise data-based decisions about when and how instruction should be changed (Kubina & Yurich, 2012; White, 1986).

Few studies to date have experimentally evaluated the use of PT with frequency-building interventions to increase fluency with mathematics skills. Chapman et al. (2005) used a multiple baseline design across three participants to investigate the impact of PT and frequency-building with adolescents with traumatic brain injuries (TBI). Mathematics skills were targeted for two of the five participants, specifically answering multiplication problems. Baseline probes consisted of a 1-minute timing to complete multiplication problems on a sheet consisting of 100 randomised problems. Computer-generated multiplication flashcards with one problem per card were used with ET to build fluency during intervention. Both participants demonstrated a significant increase in rate of correct responding to mathematics problems.

Figarola et al. (2008) used PT and ET to increase rate of correct responding while completing addition worksheets with three participants with mild learning disabilities (aged 7-8 years). Participants engaged in timed practice with target skills, were given feedback on their performance and graphed their own performance at the end of each timing. An ABAB design was employed for two of the participants. A return to baseline consisted of a timing during which feedback on performance was not provided and the experimenter graphically recorded their rates of correct responding. The results demonstrated an increase in correct responding for both participants during intervention phases, with a slight decrease during the return to baseline.

Gallagher (2006) conducted a 12-week fluency-based intervention using PT to increase rate of correct responding with multiplication problems. Rate of correct responding with target skills was assessed pre- and post-intervention using a worksheet containing 80 multiplication problems. Pre- and post-test measures were conducted with 23 participants who were aged 10 or 11. Eight participants aged 10 or 11 were exposed to intervention for the 12 weeks and the group's mean increase in rate of correct responding from pre- to post-test was compared to that of the remaining 15 participants. Worksheets with target skills, answer keys and SCCs were provided for the eight participants so that they could independently engage in ET on a daily basis. Training was provided by the experimenter prior to intervention on how to conduct ET, score, plot and understand the information they were recording. The experimenter provided feedback on a weekly basis to review progress and provide new materials. The intervention group demonstrated a mean increase of 6.38 correct responses per minute, while a mean increase of 0.27 in rate of correct responding was found for the remaining 15 participants.

As outlined in previous sections, Chiesa and Robertson (2000) used frequency-building with PT to increase fluency with mathematics skills with five participants in primary school (aged 9-10 years). Hartnedy et al. (2005) also used PT with their frequency-building intervention which was successful in increasing rate of correct responding with mathematics skills. A lack of research for fluency-based instruction has been identified in the literature. Similarly, further examination of the additional application of PT is necessary. PT provides a method of monitoring and evaluating performance on a daily basis which should facilitate the implementation of interventions. Chiesa and Robertson (2000) suggest that the database of empirical demonstrations of the effects of PT and fluency-based instruction warrants expansion and that dissemination of such research will allow teachers to see directly the effectiveness and efficiency of such programs.

1.5.4 Morningside Mathematics Fluency: Math Facts

Equally as important as the provision of empirical support for effective fluency-based instruction with mathematics skills, is the identification of key component skills which should be targeted for intervention. Throughout the literature differing target skills and materials are incorporated to evaluate each procedure. A paucity of research exists seeking to empirically validate specific curricula designed to facilitate such instruction. Identification of effective curricula should facilitate the incorporation of fluency-based instruction into educational settings. Since target skills and relevant materials are provided prior to commencing instruction, the time needed for planning and developing interventions is lessened.

The generative instruction approach to teaching academic skills involves cumulative, fluency-based instruction with skills that have been identified as key components (Johnson & Layng, 1994). Based on this approach, a number of instructional curricula have been developed to teach academic skills in this manner. Specifically, the Morningside Mathematics Fluency: Math Facts (Johnson, 2008) curricula are designed to teach key component mathematics skills, namely addition and subtraction (volumes 1 and 2) and multiplication and division (volumes 3, 4 and 5). Number families are used to teach simple addition, subtraction, multiplication and division as an alternative to teaching mathematics “tables”. This method is purported to reduce the instructional time necessary to master such skills. Once a student learns one number family (e.g., 4, 9, 13), it yields four separate math facts (i.e., 4 + 9 = 13, 9 + 4 = 13, 13 – 9 = 4, 13 – 4 = 9). The curricula are used in conjunction with frequency-building and/or PT and are designed to teach math facts fluently. Fluency aims for writing math fact answers are pre-determined within the curricula (ranging from 50-60 per minute to 80-100 per minute dependent on each lesson).

Research to date has not empirically validated the use of the Morningside curricula to increase fluency with mathematics component skills or tested generalised outcomes associated with their use. However, Johnson and Street (2013) describe informal evaluations of their use across three schools in the US. The Morningside Math Facts curricula were implemented in conjunction with additional curricula designed to build accuracy and fluency with further mathematics skills (e.g., fractions, whole number computation, and number reading). As a result, students' scores on standardised assessments of mathematical ability are reported to have increased across the three schools. Since positive outcomes have been reported within informal evaluations and the need for empirically validated mathematics interventions has been noted (Poncy et al., 2013), empirical validation of such curricula is warranted.

1.6 Moderators of Fluency-Based Instruction

Research investigating fluency-based interventions with mathematics skills has demonstrated positive outcomes to date, predominantly the efficacy of such interventions to increase rate of correct responding with targeted skills (Gross et al., 2013; Hartnedy et al., 2005; Poncy et al., 2010; Poncy et al., 2013). However, the strength of the outcomes reported has varied across studies. A number of studies report that certain fluency-based interventions were not effective for *all* participants to increase fluency with target skills. Bliss et al. (2010) evaluated a Taped Problems (TP) intervention to increase fluency with multiplication problems with six participants in fifth grade. They found that TP was effective in increasing digits correct per minute (DCM) across four of six participants. The authors suggest that TP is an effective procedure for increasing DCM for some, but not all students. Miller et al. (2011) evaluated the effects of an intervention designed to increase fluency with addition math facts using a multiple-baseline design across math fact sets. The intervention was implemented with 19 participants in the second grade and found to be effective for 15 with the remaining four showing few gains.

Such findings imply that fluency-based instruction may not be equally as effective across *all* students and that additional variables may impact the ability of such instruction to achieve best outcomes. Codding et al. (2009) noted that although their analysis of fluency-based interventions demonstrated effectiveness in improving performance, individual differences and implementation variables can affect the outcomes of interventions. Mong and Mong (2012) maintain that research is warranted to facilitate the selection of the most effective interventions and the matching of instruction to individual students' needs. As such, research should identify variables which impact effectiveness of fluency-based instruction. Information on such variables prior to implementation will allow for the most effective evidence-based interventions to be implemented from which optimal outcomes can be achieved. Research to date has implicated a number of variables which are in need of further investigation.

1.6.1 Mathematical and Cognitive Ability

Students' current mathematical ability may be considered a critical measure when developing and planning interventions for individual students. Scholin and Burns (2012) assert that growth in any academic skill is likely to be a factor of the interaction between the skill base of the student and intervention; however, they suggest that research has failed to identify any student-centred aptitude that specifically relates to intervention effectiveness.

A number of methods of assessing student skill base can be used. Standardised norm-referenced assessments are typically administered annually and provide the basis for determining whether students are making adequate yearly progress (Johnson & Street, 2013). These tests provide scores on a broad range of skills within each academic domain measuring aspects of learning which are targeted in general education settings. Students' scores across subtests of specific mathematical abilities can identify individual strengths and weaknesses which are used to inform and facilitate intervention planning.

Additional methods of assessment can be used to inform intervention development, in particular fluency-based instruction. Burns, Codding, Boice and Lukito (2010) purport that sampling students' levels of correct responding with instructional materials can inform instructional planning. Pre-test levels of accuracy and fluency with such materials should inform the appropriateness of fluency-based instruction for individual students. Results of their meta-analytic review of mathematics interventions, targeting both acquisition and fluency, demonstrated that fluency-based interventions had a small to moderate effect with students who had lower pre-test fluency with targeted skills. Conversely, acquisition interventions resulted in larger effect sizes among students with lower pre-test fluency. These findings suggest that fluency-based interventions are not as effective for students who present with low levels of fluency prior to intervention and may have benefited more from interventions targeting acquisition of mathematics skills. However, to date, few studies have examined the consistency with which fluency scores on computational tasks can be used to guide instructional programming (Burns, VanDerHeyden & Jiban, 2006) or can moderate the effectiveness of interventions.

Geary et al. (2012) emphasise the importance of general cognitive abilities including working memory and processing speed that affect learning in mathematics. Chong and Siegel (2008) found that students who had math fact fluency deficits showed persistent deficits in processing speed from the second to the fifth grade. Measurement of such cognitive abilities can play a role in predicting mathematics achievement and the identification of deficits that contribute to poor math achievement (Geary et al., 2012). However, no research to date has investigated the role of processing speed within the context of fluency-based interventions and how this ability might impact their effectiveness.

1.6.2 Age, Grade and Gender

A number of research findings indicate that student age, grade and gender should be considered when developing interventions with the goal of increasing fluent performances. Participant age has been shown in previous research to impact performance on fluency tasks. Kavé (2006) conducted word fluency tests (a three-letter phonemic fluency task and a three-category semantic fluency task) with 150 children to examine performances related to participant age. Five age groups were examined (8-9, 10–11, 12–13, 14–15, and 16–17 years) with 30 participants in each group. Analysis of outcomes demonstrated an incremental increase in performance according to increased age indicating that age plays an important role in individuals' ability to perform fluently with specific tasks.

Sak and Maker (2006) investigated mathematical ability in relation to participant age and school grade with 841 first to fourth grade students. Their findings indicated that the contribution of age to fluent performances was low at all grade levels but that there was a statistically significant difference among grades for fluency with mathematics skills. These findings suggests that student age and school grade may be important variables to consider when choosing fluency or rate of correct responding as a goal of instruction, specifically when selecting performance criteria for individual students. Further investigation is warranted to examine the impact of each variable on intervention effectiveness and to inform on how fluency-based instruction should be modified to suit students of differing ages and within differing school grades.

Previous research has also indicted the potential for gender differences in mathematics fluency (Carr et al., 2008; Royer et al., 1999). Carr et al. (2008) found that in a sample of 241 second grade students, girls were found to have lower fluency with mathematics skills than boys and reported that this likely contributed to boys' faster acquisition of mathematical skills during early elementary school years. While a number of studies to date have examined the relationship between participant age, grade and gender and the ability to achieve fluent performances across skills, no research has been conducted to investigate if such variables moderate participants' ability to achieve higher fluency performances with intervention.

1.6.3 Intensity of Instruction

A limited amount of research has been conducted to investigate the intensity at which interventions are implemented as a variable which impacts their effectiveness (Codding, Burns & Lukito, 2011; Duhon et al., 2009; Mellard, McKnight and Jordan, 2010). However, consideration of intensity has potential implications for intervention in both research and applied practice within educational settings. With regard to research, dependent measures are suggested to be more sensitive to a stronger intervention "dose" (i.e., minutes, frequency or duration of instruction) when assessing the effects of applied experimental research (Lipsey & Hurley, 2009).

Throughout educational settings, more intensive instruction is frequently applied with students who present with learning difficulties in an academic domain (Codding et al., 2009; Johnson & Street, 2013). Miller et al. (2011) suggest that students who fail to develop automaticity during intervention be exposed to alternative or supplemental procedures or greater levels of intensity. Further, Duhon et al. (2009) suggest that, during intervention, a student's response is measured to evaluate the outcomes of intervention but that intensity should also be evaluated to provide a context for those outcomes. Observation of students' responses to differing levels of intensity has been acknowledged as important for decision making when implementing interventions (Ardoin, Witt, Connell & Koenig, 2006) so that the intensity at which that intervention produces optimal outcomes can be identified.

Investigations of intervention intensity and its impact on intervention outcomes are emerging in the literature. Duhon et al., (2009) evaluated the impact of increased intensity of a fluency-based intervention with mathematic skills using a multiple-baseline design across three participants. Intensity was quantified as frequency of sessions implemented per day and was increased based on participants' responsiveness to intervention (i.e., if no treatment effect was evident). Increasing the frequencies of sessions for each participant resulted in higher rates of correct responding with targeted mathematics skills.

Hale (2009) investigated the impact of an intervention to build fluency with mathematics skills at differing frequencies of implementation. Participants were 98 students in fourth grade and were randomly assigned to one of three groups. Groups were exposed to intervention either twice per day, once per day or once every other day for 20 days. Mean math fluency scores were significantly higher for the twice per day group in comparison to the every other day group. These findings highlight the importance of considering intensity when developing interventions and its ability to significantly impact outcomes. However, to date, it is an area that has had limited empirical consideration and further research is necessary to better understand its impact on fluency-based instruction.

1.6.4 Assessment of Moderators of Instruction

The identification and examination of variables which impact the effectiveness of fluency-based instruction is essential. Equally as important as empirically validated procedures for increasing fluency, is the identification of individual students for whom they are most effective and the intensity at which they should be implemented to achieve best outcomes. Research investigating individual differences and implementation variables, and their impact on intervention effectiveness, will inform best practice within applied experimental research and the implementation of interventions in educational settings. However, few studies to date have investigated these variables.

Investigations of moderation effects can determine when or for whom an independent variable most strongly or weakly affects a dependent variable (Baron & Kenny 1986; Frazier et al. 2004; Kraemer et al. 2002; Wu & Zumbo, 2008). Such analyses can be conducted when investigating whether an instructional method is equally effective for students who present with varying levels of potentially moderating variables and can explain the strength of the causal relationship between the intervention and outcomes (Wu & Zumbo, 2008). Using such analyses, in depth investigations of the ability of individual differences (e.g., students of differing ages and with differing abilities) to moderate the effectiveness of interventions can be conducted. Further, interventions implemented at differing levels of intensity can be investigated to examine its moderating effects of intensity of intervention on outcomes.

Analyses of moderating variables necessitate large sample sizes so that varying levels of the potentially moderating variable can be assessed. However, SSRD's, with smaller sample sizes, are the predominant method by which fluency-based mathematics interventions are examined (Codding et al., 2009). Research is necessary to investigate the application of fluency-based interventions with larger sample sizes so that moderators of instruction can be identified. The identification of such variables, and how they impact outcomes of interventions, is essential to inform planning and implementation of the most effective and efficient interventions.

1.7 Summary and Research Aims

Researchers and practitioners in the area of behavioural fluency have proposed a significant rationale for the definition of mastery in terms of fluent performance within educational settings. Several outcomes (i.e., endurance, stability, application, retention and generativity) essential to learning and education, have been associated with the attainment of fluent responding with key component academic skills (Binder, 1996; Johnson & Street, 2013). Additionally, a number of studies have identified links between fluent component skills and performances on measures of overall ability within that academic domain (Begeny et al., 2012; Carr, et al., 2008; Hughes, Beverley & Whitehead, 2007). However, few studies to date have empirically demonstrated the occurrence of such outcomes as a result of fluency-based instruction. Further, the need for empirically validated fluency-based interventions, which are effective for all students, has been emphasised (Codding et al., 2009; Poncy et al., 2013).

The current research aims to contribute to the literature seeking to (i) empirically validate fluency-based interventions targeting key component mathematics skills, (ii) evaluate the moderating effects of individual differences and implementation variables to inform the design and application of such interventions, (iii) investigate critical learning outcomes associated with fluent performances, and (iv) examine the impact of building fluent mathematics skills on standardised measures of overall mathematical ability. Chapters 2 and 3 employ between-group designs to examine the impact of frequency-building, PT and the Morningside mathematics curricula to increase fluency with mathematics skills. The impact of intervention on critical learning outcomes and standardised measures of mathematical ability are investigated. Chapters 4 and 5 further evaluate fluency-based instruction, with a focus on the moderating effects of individual differences and intensity.

Chapter 2:

An Evaluation of Frequency-Building Instruction to Increase Mathematics Skills and Associated Outcomes

2.1 Introduction

Research in the area of behavioural fluency indicates that progression through mathematics curricula depends on the achievement of fluency with component skills. The ability to achieve mastery with complex mathematical problems is purported to improve when the basic pre-requisites are successively built upon, achieving fluency with each skill. Binder (1996) also outlines beneficial outcomes associated with fluent performance, purporting improvements in learners' ability to maintain attention to tasks over extended durations of performance (i.e., endurance) and in the face of distraction (i.e., stability), retain what has been learned (i.e., retention), apply tool skills to more advanced tasks or new situations (i.e., application) and develop complex behavioural repertoires without explicit instruction (i.e., generativity). Such findings indicate a necessity for emphasis on learning component skills both accurately and fluently, for all students, so that they can progress smoothly and achieve an academic growth trajectory that leads to success.

Geary et al., (2012) assessed mathematics achievement over five years (from kindergarten to fifth grade) with children with a mathematical learning disability (MLD, n = 16), persistent low achievers (LA, n = 29) and typical achievers (TA, n = 132). The purpose of the study was to document growth in mathematical ability across all groups. Standardised mathematics achievement tests were administered annually from kindergarten to fifth grade. Rate of change in achievement scores represented participants' growth in math achievement. Both the MLD and LA groups showed slow across-grade growth in math achievement. Analyses identified fluency of number processing and ability to emit basic facts as mediators of group differences in growth.

Considering the emerging evidence associated with learning skills fluently (e.g., Chiesa & Robertson, 2000; Poncy et al., 2013), a first-line intervention for students struggling with mathematics may be to implement instructional programmes that provide multiple opportunities to practice basic facts (Codding et al., 2010). Given the findings that fluency of number processing and basic facts mediate growth in mathematical achievement, research is warranted to examine intervention on such skills in relation to their ability to accelerate growth rates in mathematics achievement among students who are failing to keep pace with their peers.

In order to intervene with mathematics skills and increase fluent responding, research is also necessary to identify the most effective interventions and curricula to do so. Empirically validated interventions and curricula permit educators to make informed decisions about the most effective and efficient methods of instruction. The current study aimed to evaluate a curriculum designed to build fluency with component mathematics skills not previously examined in the literature. Frequency-building using the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum was implemented with school children who were failing to keep pace with their peers. The intervention was evaluated in terms of its ability to increase fluency as measured by rate of correct responding with targeted basic math facts.

In addition to rate of correct responding, measures of endurance, stability and application were recorded pre- and post-intervention to investigate outcomes associated with building fluent performances. Rate of correct responding is the primary outcome measure of frequency-building interventions investigated throughout the literature (Codding et al., 2009). Few studies have investigated the impact of fluent responding on endurance, stability or application and the emergence of such outcomes has not previously been evidenced using pre- and post-test measures.

Few studies to date have investigated the impact of building fluency with component mathematics skills on standardised assessments of mathematical ability. Previous research has identified a link between fluency with component mathematics skills and general mathematical ability (Carr et al., 2008; Carr & Alexeev, 2011). Further, fluency of number processing and ability to emit basic facts have been demonstrated as important contributory factors to growth in mathematical achievement as measured by such standardised assessments (Geary et al., 2012). The current research sought to investigate the impact of building fluency with math facts on mathematics subtests of the Wechsler Individual Achievement Test, Second Edition (WIAT-II; Wechsler, 2005).

Single-subject research designs are the predominant method applied to evaluate frequency-building interventions. Some group designs have been used but without sufficient sample sizes to allow statistical analysis of between-group differences in scores on outcome measures. Such research has demonstrated positive outcomes in relation to frequency-building interventions and replication on a larger scale is warranted. The current research employed a between-groups design to evaluate the effects of the intervention in comparison to a control group who received treatment as usual (TAU) only. Pre- and post-test measures of the WIAT-II mathematics subtests, fluency with targeted math skills, endurance, stability and application were recorded for both groups. Between-groups analyses were conducted to investigate differences in scores on post-test measures.

2.2 Method

2.2.1 Participants and Setting

Twenty-eight males with a mean age of 10 years 1 month (SD = .64, range: 9-11.4) took part in the study. The participants attended an all boys primary school and were in fourth and fifth grade when the intervention took place. Participants were identified for inclusion within the study by their teachers if they demonstrated difficulties in performing at an age equivalent level on the mainstream mathematics curriculum and were receiving daily remedial support in mathematics. Students were only included in the study if they scored below 100 on the WIAT-II tests of mathematics ability. Participants' mean standard composite score (comprising of two mathematics subtests) on the WIAT-II was 86.6 (SD = 9.23, range: 61-99). Parental consent was obtained for all participants included in the study.

The intervention took place during school hours with three to four participants and one experimenter in each session. Sessions were conducted with fourth and fifth grade groups separately. Grade groups were then further broken down into the smaller groups of three to four participants to implement the intervention. Sessions were conducted in a small classroom with all participants sitting at a semi-circular table and one instructor. During pre- and post-testing, a second observer was present in the classroom for 29% of observations to record interobserver agreement.

2.2.2 Materials

Each participant receiving intervention was allocated a folder with materials for frequency-building. Materials included a sticker chart to self-monitor and reinforce achievement of fluency aims (see Appendix A). The chart consisted of three columns. The first column listed each worksheet in sequence and the second column contained the aim for each worksheet. When the aim for each worksheet was achieved, participants received a sticker which they placed in the third column next to their aim. The folders also included the worksheets to be completed within the session. Digital timers were used to conduct timings.

2.2.2.1 Curriculum

The Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum was used to teach component skills in mathematics. This curriculum is designed to build fluency with multiplication and division computation. Fact families are used to build fluency with multiplication and division for single digits. A work sheet containing target fact families is provided so that each fact family can be recited both accurately and fluently. The curriculum includes a fluency aim of accurately reciting each fact family within 4-6 seconds before progressing to pencil and paper worksheets.

Pencil and paper worksheets each consist of 100 problems presented in random order pertaining to 36 fact families and multiplication and division by one and zero. The fluency aim for number of correct responses per minute for each worksheet is 50-60per minute. The curriculum also includes cumulative and review worksheets which consist of problems pertaining to fact families learned in previous sessions. The aims set by the curriculum are 60-70 correct responses per minute for cumulative worksheets and 70-80 correct responses per minute for review worksheets. There are a total of 84 fluency aims to achieve throughout the complete curriculum. Table 2.1 shows the fact families and problems taken from the curriculum that were targeted during intervention (samples of worksheets from the curriculum are included in Appendix B).

Fact family	Target problems	Practice materials	Fluency aims
Multiply & divide with 0	Multiply & divide 0 with digits 1-9	Missing number & New facts worksheet	50-60 p/min
Multiply & divide with 1	Multiply & divide 1 with digits 1-9	Missing number & New facts worksheet	50-60 p/min
		Cumulative worksheet	60-70 p/min
2 2 4 2 3 6 2 4 8	$2 \times 2 = 4$ $2 \times 4 = 8$ $4 \div 2 = 2$ $4 \times 2 = 8$ $2 \times 3 = 6$ $8 \div 2 = 4$ $3 \times 2 = 6$ $8 \div 4 = 2$ $6 \div 2 = 3$ $6 \div 3 = 2$	Box sheet (learn orally)	Say fact family in 4-6 seconds
		Missing number worksheet & New facts worksheet	50-60 p/min
		Cumulative worksheet	60-70 p/min
2 5 10 2 6 12	$2 \times 5 = 10$ $2 \times 6 = 12$ $5 \times 2 = 10$ $6 \times 2 = 12$ $10 \div 2 = 5$ $12 \div 2 = 6$ $10 \div 5 = 2$ $12 \div 6 = 2$	Box sheet (learn orally)	Say fact family in 4-6 seconds
		Missing number worksheet & New facts worksheet	50-60 p/min
		Cumulative worksheet	60-70 p/min

Table 2.1 Mathematics skills targeted during intervention

Fact family	Target problems	Practice materials	Fluency aims
2 7 14 2 8 16	2 × 7 = 14 2 × 8 = 16 7 × 2 = 14 8 × 2 = 16 14 ÷ 2 = 7 16 ÷ 2 = 8 14 ÷ 7 = 2 16 ÷ 8 = 2	Box sheet (learn orally)	Say fact family in 4-6 seconds
		Missing number worksheet & New facts worksheet	50-60 p/min
		Cumulative worksheet	60-70 p/min
2 9 18 3 3 9 3 4 12	2 × 9 = 18 3 × 4 = 12 9 × 2 = 18 4 × 3 = 12 18 ÷ 2 = 9 12 ÷ 3 = 4 18 ÷ 9 = 2 12 ÷ 4 = 3 3 × 3 = 9 9 ÷ 3 = 3	Box sheet (learn orally)	Say fact family in 4-6 seconds
		Missing number worksheet & New facts worksheet	50-60 p/min
		Cumulative worksheet	60-70 p/min
3 5 15 3 6 18	3 × 5 = 15 3 × 6 = 18 5 × 3 = 15 6 × 3 = 18 15 ÷ 3 = 5 18 ÷ 3 = 6 15 ÷ 5 = 3 18 ÷ 6 = 3	Box sheet (learn orally)	Say fact family in 4-6 seconds
		Missing number worksheet & New facts worksheet	50-60 p/min
		Cumulative worksheet	60-70 p/min

Table 2.1 continued. Mathematics skills targeted during intervention

2.2.3 Design

A between-group design was used to evaluate the efficacy of the frequency-building intervention to increase fluency with component mathematics skills. Participants across groups were matched according to current grade, composite mathematics scores on the WIAT-II and age and were subsequently randomly assigned to either an experimental (n=14) or control (n=14) condition. Participants were matched with a peer in the same grade (dyads) and with those whose standard score on the WIAT-II mathematics subtests was no more than ten points more or less than their own. After meeting these criteria, participants closest in age were then matched. Table 2.2 shows details of experimental participants and their matched controls.

Dependent measures were recorded for all participants. The Experimental Group received the frequency-building intervention while both groups participated in classroom instruction and learning support classes as usual (i.e., the Control Group represented a TAU group). Once a participant in the Experimental Group had completed the intervention, dependent measures were administered again, to that participant and his matched control. The intervention was implemented over 32 weeks, inclusive of pre- and post-testing, with a mean of 23.4 sessions (SD = 4.01) implemented with participants in the Experimental Group.

Experimental Group					Matched Control Group				
Age	Grade	WIAT-II Numerical Operations	WIAT-II Mathematical Reasoning	WIAT-II Composite Standard Score	Age	Grade	WIAT-II Numerical Operations	WIAT-II Mathematical Reasoning	WIAT-II Composite Standard Score
10.4	5	101	84	91	11.1	5	94	90	90
10.10	5	98	90	92	10.9	5	95	90	91
10.9	5	103	97	99	10.3	5	94	95	93
10.11	5	69	69	66	10.2	5	73	58	61
10.5	5	98	67	81	10.8	5	89	78	82
11.4	5	99	102	99	10.10	5	98	84	89
9.11	4	101	74	86	10.3	4	79	76	76
9.5	4	95	91	91	9.3	4	103	82	91
9.10	4	98	82	88	9.3	4	100	82	89
10.1	4	91	87	87	10.6	4	93	82	86
9.7	4	102	87	93	9.6	4	98	91	93
9	4	85	88	85	9.8	4	101	74	86
9.6	4	111	79	94	9.5	4	105	91	97
10.1	4	88	68	76	10.6	4	73	76	72

Table 2.2 Participant dyads across Experimental and Control Groups.

2.2.4 Dependent Measures

Dependent variables included the WIAT-II, fluency with targeted mathematics skills and three of the fluency outcomes defined by Binder (1996), namely endurance, stability and application.

2.2.4.1 WIAT-II

Participants were assessed using the WIAT-II as a standardised measure of mathematics ability. Both Numerical Operations and Mathematical Reasoning subtests were administered. The Numerical Operations subtest is a pencil and paper test with items that progress in complexity assessing numerical identification, counting, numeral writing, simple addition and subtraction, integer arithmetic, multi-digit addition and subtraction, single digit multiplication and division, fractions, decimals and percentages as well as integers. Mathematical Reasoning is an orally presented verbal problem-solving test with pictures. This test assesses counting, comparison, simple addition and subtraction word problems, mathematical language, interpretation of charts, completion of patterns, knowledge of measures and money, fractions, decimals, probability and mental rotation.

2.2.4.2 Fluency

A review worksheet assessed fluency with targeted mathematics skills. Each participant was assessed using this worksheet which provided multiple exemplars of multiplication and division problems which were targeted throughout the frequency-building intervention. One hundred problems relevant to all 12 fact families were presented in a random order on the worksheet. Participants completed as many problems as they could during a 1-minute timing. Rate of correct responding per minute was calculated by the experimenter subsequent to administration. All math problems required one or two digit answers. A correct response was recorded if all digits in the answer to the problem were correct. Responses were scored as incorrect if any digits in the answer to a problem were incorrect, if digits were omitted or placed in the incorrect order.

2.2.4.3 Endurance

In order to evaluate the ability to sustain a steady performance over an increased length of time, participants completed as many problems as they could using pencil and paper worksheets during a 5-minute timing. Four worksheets containing problems that were presented during the intervention with the Experimental Group were presented with one hundred problems on each. Measures of both rate of correct responding (Brady & Kubina, 2010) and on-task behaviour (McDowell & Keenan, 2001) were recorded.

2.2.4.3.1 Rate of Correct Responding

Rate of correct responding per minute was calculated to assess if participants could sustain a high rate of correct responding during prolonged timings to which they were not exposed during frequency-building sessions. As with the measure of fluency, a correct response was recorded if all digits in the answer to the problem were correct. Responses were scored as incorrect if any digits in the answer to a problem were incorrect, if digits were omitted or placed in the incorrect order.

2.2.4.3.2 Systematic Observation of On-task Behaviour

Each participant was also systematically observed during the same 5-minute timing using the Behavioral Observation of Students in Schools (BOSS; Shapiro, 2004). The BOSS is a measure that is used to directly observe active engagement on academic tasks (Chafouleas, Sanetti, Kilgus & Maggin, 2012). Proponents of fluency suggest that achievement of high performance frequencies increases individuals' ability to maintain attention to a task over extended durations of performance. For this reason, operational definitions from the BOSS were used to observe active engagement in tasks during extended timings to assess this critical learning outcome.

The BOSS divides on-task behaviour into active engaged time (AET) and passive engaged time (PET). Active engaged time is defined as when a student is actively engaged in academic responding (e.g., reading aloud or writing). Passive engaged time is defined as when a student is passively attending (e.g., listening during instruction). As participants should be actively engaged (i.e., writing answers to multiplication and division problems) when completing written mathematics problems, only AET was recorded. Momentary-time sampling with ten second intervals was used to measure the percentage of intervals participants were observed to be actively engaged.

2.2.4.4 Stability

In order to evaluate the ability to sustain a steady performance over an increased length of time in the presence of distractors, 3-minute timings were conducted during which participants completed pencil and paper worksheets with problems presented during the intervention phase. However, during each participant's stability timing, two or three students were instructed to complete oral math problems aloud within a small group next to them. This was implemented in an effort to create a distraction for the target student taking the stability test. Similar to measures of endurance, the worksheets were scored by the experimenter and rate of correct responding per minute was calculated. Momentary-time sampling, using operational definitions from the BOSS, was again conducted to measure the percentage of intervals participants were observed to be actively engaged.

2.2.4.5 Application

To assess participants' ability to apply component skills targeted during intervention to more complex mathematics problems, a test consisting of more complex single and double digit multiplication and division problems was administered (see Appendix C). Problems included in the test were taken from the primary curriculum math book for the previous year. All of the problems relied on division and multiplication of digits within fact families targeted during the fluency intervention. Participants completed as many problems as they could on the test during a 2-minute timing. The test was scored by the experimenter and digits correct per minute (DCM) was calculated. Each correct digit within an answer was scored as correct if it was placed in the correct position in the answer. Digits were scored as incorrect if an incorrect digit was written, if it was incorrectly placed in the answer or if it was omitted

2.2.4.6 Social Validity

A brief questionnaire to assess social validity was administered subsequent to the intervention (see Appendix D). Eleven of the fourteen participants in the experimental group completed the questionnaire. Questions focused on the participants' enjoyment of fluency training, most difficult and easiest elements of the intervention and whether or not they thought it had helped them. Participants were required to select "yes" or "no" after reading a question related to the intervention.

2.2.5 Inter-Rater Reliability

2.2.5.1 Rate of Correct Responding

Thirty percent of the worksheets were independently scored by two individuals to examine inter-rater reliability. Inter-rater agreement was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplied by one (Codding, Archer & Connell, 2010). Percentage agreement for number of correct responses on worksheets was 100%.

2.2.5.2 Observation of On-task Behaviour

Inter-observer agreement was conducted for 29% of observations using the BOSS. Two observers, the experimenter and a trained independent observer, independently collected inter-observer agreement data during both endurance and stability timings. The independent observer was blind to the group to which each participant had been assigned. Each observer rated whether the participant was actively engaged or off-task using momentary-time sampling with ten second intervals. The end of each interval was signalled using an audio cue which both observers listened to through headphones. Inter-observer agreement was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplied by one hundred. Percentage agreement for number of the number of intervals observed on- or off-task was 98.8%.

2.2.6 Procedure

2.2.6.1 General Procedures

Participants were exposed to the frequency-building intervention for twenty minute sessions, one day per week until they had achieved 26 fluency aims targeted for intervention. The 26 aims pertained to the first 12 fact families in the curriculum, multiplying with 0, and multiplying and dividing with 1 (see Appendix B). Fluency aims (i.e., target number of correct responses per minute) were pre-determined by the curriculum for each worksheet. Table 2.1 illustrates skills targeted with the Experimental Group. During each session Explicit Timing (ET) was conducted with participants while they completed worksheets from the curriculum. Participants in both the Experimental Group and the Control Group continued with typical classroom instruction and learning support classes as usual. As each experimental participant achieved all 26 targeted aims, post-tests were conducted with both participants in the dyad.

2.2.6.2 Curriculum Start Point Allocation

Prior to implementing the intervention, one-minute timed probes were conducted with the first two targets in the curriculum to investigate whether participants could achieve fluency targets as outlined by the curriculum. This was conducted to ensure that no participant would start at a point in the curriculum at which they were already fluent. No participant reached fluency aims on timed probes and all were allocated a start point at the beginning of the curriculum.

2.2.6.3 Frequency-Building Sessions

During the first session, folders containing the instructional materials were allocated and the general procedure was explained to the group. All participants were told that they would receive a sticker each time they reached a fluency aim and would continue with the sessions until they had achieved all of their aims. During subsequent sessions, participants were instructed to open their folders and find the worksheet they were currently working on using their sticker charts as a reference. The pre-determined fluency aims were also identified by participants using the chart.

Before participants began 1-minute timings with each pencil and paper worksheet, they were required to learn each fact family orally. It was explained that they should practice reciting each math fact as fast as they could. The participants were also informed that their aim was to recite each fact family in 4-6 seconds. Each participant practiced this independently while the remaining participants engaged in either ET with paper and pencil worksheets or practiced learning their own targets orally. The experimenter then tested each participant to verify that they had achieved their aim of reciting each fact family in 4-6 seconds.

When participants were working on pencil and paper worksheets, they identified their aim using their sticker chart and marked an X on their worksheet as a visual prompt to indicate how many problems should be completed correctly to achieve that aim. The experimenter monitored participants to ensure that everyone in the group was working on the correct target and had identified the correct aim before starting. When the group was ready, the timing began. Each participant was instructed to place their pencil at the start point on their worksheet. They were reminded that they needed to answer as many problems correctly as they could within one minute and should aim to beat their score from the last timing. The experimenter set the timer for one minute, said "Let's begin" and started the digital timer. All of the participants within the small group session completed their own worksheets at the same time.

2.2.6.4 Corrective Feedback

No corrective feedback was delivered during timings; however, participants received praise throughout the timing contingent only on active engagement in the task. Once a timing was complete, the group was instructed to "drop their pencils", count how many problems they had completed and to signify any incorrect responses by drawing a circle around it. The experimenter monitored the group to verify number of correct and incorrect responses and to provide corrective feedback on errors with each participant individually. The experimenter identified incorrect responses and presented the relevant problems orally. Least-to-most prompts were used until the participant could emit the correct response.

Praise, the opportunity to choose a sticker and progression to the next worksheet were contingent on the attainment of each fluency aim. When a fluency aim was not attained, additional timings were subsequently completed on that worksheet. One-minute timings were used for all paper and pencil worksheets; therefore, participants did not have to work on the same targets as their peers in the group. Each participant could progress to the next worksheet as soon as they achieved their aim Participants received praise for higher rates of responding and for correct responding (e.g., “You beat your score from the last timing, well done” or “You answered all of the problems correctly, well done”).

2.3 Results

The Experimental Group progressed through the frequency-building intervention with the majority (71%) of participants achieving all 26 fluency aims. The remaining 29% achieved between 13 and 24 fluency aims. Fluency aims ranged from 50-70 correct responses per minute across the target worksheets. Table 2.3 provides information on the number of aims achieved and number of sessions completed with each participant.

One-way between-group analyses of covariance (ANCOVA) were conducted to compare the effectiveness of frequency-building on participants’ post-test scores for all dependent variables as compared to scores attained by the Control Group at post-test. Participants’ pre-test scores were used as the covariates in the analyses. Preliminary checks were conducted for each ANCOVA to ensure that there was no violation of assumptions. A correction to control for multiple testing was not included in statistical analyses since it is recommended that corrections be used when investigators are searching for significant relationships but without pre-established hypotheses (Armstrong, 2014; Perneger, 1998). The current research investigated specific hypotheses outlined prior to data collection and statistical analyses.

Participants in Experimental Group	Number of sessions completed	Number of aims met (50-70 correct responses per minute)
1	16	26
2	25	24
3	16	26
4	28	12
5	23	26
6	22	26
7	23	26
8	28	22
9	21	26
10	23	26
11	24	26
12	24	13
13	25	26
14	30	26

Table 2.3 Number of sessions and aims achieved by the Experimental Group

Significant differences between groups were found for post-test scores on the Mathematical Reasoning subtest of the WIAT-II and for post-test rates of correct responding on tests of fluency, endurance and stability. No significant differences were found for post-test composite scores of mathematical ability on the WIAT-II or on the Numerical Operations subtest. There were no significant differences in post-test scores for the BOSS during endurance or stability timings or for rates of correct responding with tests of application. Paired samples t-tests were conducted for both the Experimental and Control groups' pre- and post-test scores to investigate increases in scores on dependent variables within each group. Table 2.4 summarises the mean performance for the Experimental and Control groups on each dependent measure at both pre- and post-tests.

2.3.1 WIAT-II

One-way between-group analyses of covariance were conducted for post-test scores on both mathematics subtests as well as participants' composite scores. A significant difference between the two groups was found on the Mathematical Reasoning sub-test, $F(1, 25) = 4.48$, $p = .044$, partial eta squared = .152. The Experimental Group scored higher than the Control Group at post-testing. Paired samples t-tests found a significant increase in the Experimental Group's scores on the Mathematical Reasoning subtest of the WIAT-II from pre-test ($M = 83.2$, $SD = 10.8$) to post-test ($M = 88.5$, $SD = 8.08$), $t(13) = -2.52$, $p = .025$, $\eta^2 = .333$. No significant increase was found for the Control Group from pre-test ($M = 82.1$, $SD = 9.57$) to post-test ($M = 82.5$, $SD = 9.6$), $t(13) = .211$, $p = .836$). No significant differences between groups were found for the Numerical Operations or Composite mathematics score nor were there significant increases in scores on the same measures from pre- to post-testing for either group. Table 2.4 shows the mean performances on each subtest at pre- and post-testing for both the Experimental and Control Group.

2.3.2 Fluency

A significant difference was found between post-test scores on targeted mathematics skills between groups, $F(1, 25) = 19.3$, $p < .001$, partial eta squared = .436, showing that the Experimental Group's rate of responding was significantly

Dependent variable	Time period	Experimental Group-Frequency-building		Control Group-Treatment as usual	
		N	Mean *(SD)*	N	Mean *(SD)*
WIAT-II composite score	Pre-test	14	87.7 *(8.89)*	14	85.4 *(9.75)*
	Post-test	14	89.8 *(6.92)*	14	84.9 *(10.3)*
Mathematical Reasoning (WIAT-II)	Pre-test	14	83.2 *(10.8)*	14	82.1 *(9.57)*
	Post-test	14	88.5 *(8.08)*	14	82.5 *(9.6)*
Numerical Operations (WIAT-II)	Pre-test	14	95.6 *(10.1)*	14	92.5 *(10.5)*
	Post-test	14	94.4 *(7.94)*	14	91.3 *(11.3)*
Fluency	Pre-test	14	12.9 *(7.65)*	14	11.2 *(9.42)*
	Post-test	14	33.1 *(13.5)*	14	17.4 *(8.85)*
Endurance (Rate of correct responding)	Pre-test	14	12.6 *(7.89)*	14	12.8 *(10.4)*
	Post-test	14	39.6 *(9.59)*	14	20.3 *(9.2)*
Endurance (BOSS)	Pre-test	14	78 *(19)*	14	77.4 *(22.1)*
	Post-test	14	99.3 *(1.9)*	14	98.6 *(2.15)*
Stability (rate of correct responding)	Pre-test	14	16.7 *(9.45)*	14	15.7 *(10.4)*
	Post-test	14	45.5 *(6.9)*	14	28.8 *(7.08)*
Stability (BOSS)	Pre-test	14	71.4 *(29)*	14	64.7 *(27.4)*
	Post-test	14	95.2 *(4.78)*	14	92.3 *(19.2)*
Application	Pre-test	14	4.93 *(3.26)*	14	4 *(3.85)*
	Post-test	14	13.8 *(4.86)*	14	11.1 *(4.91)*

Table 2.4 Mean performance for the Experimental and Control Group on each dependent measure at both pre- and post-testing

higher than that of the Control Group. Paired samples t-tests showed a statistically significant increase for the Experimental Group in rate of correct responding on the measure of fluency with targeted mathematics skills from pre-test (M = 12.9, SD =

7.65) to post-test ($M = 33.1$, $SD = 13.5$), $t(13) = -7.73$, $p < .001$, $\eta^2 = .$ .832. There was also a significant increase for the Control Group from pre-test ($M = 11.2$, $SD = 9.42$) to post-test ($M = 17.4$, $SD = 8.85$), $t(13) = -3.43$, $p = .004$, $\eta^2 = .495$. Table 2.4 shows the mean performances measures of fluency at pre- and post-testing for both the Experimental and Control Group.

2.3.3 Endurance

One-way between-group analyses of covariance were conducted to assess the impact of frequency-building on post-test scores for rate of correct responding and observed on-task behaviour. There was a significant difference between the two groups on post-test rates of correct responding, $F(1, 25) = 54.2$, $p < .001$, partial eta squared = .68. The Experimental Group demonstrated a statistically significant increase in rate of correct responding during endurance timings from pre-test ($M = 12.6$, $SD = 7.89$) to post-tests ($M = 39.6$, $SD = 9.59$), $t(13) = -11.9$, $p < .001$, $\eta^2 = .922$. A significant increase in rate of correct responding was also found for the Control Group from pre-test ($M = 12.8$, $SD = 10.4$) to post-test ($M = 20.3$, $SD = 9.21$), $t(13) = -4.56$, $p = .001$, $\eta^2 = .613$. Table 2.4 shows the mean performances measures of endurance at pre- and post-testing for both the Experimental and Control Group. Both groups demonstrated significant improvements; however, participants who had been exposed to frequency-building sustained a higher rate of correct responding than those who received treatment-as-usual only.

There was no significant difference between groups on percentage of intervals observed on-task, $F(1, 25) = .77$, $p = .389$, partial eta squared = .030. Both groups were observed to stay on-task for a higher percentage of intervals at post-tests. The Experimental Group mean percentage of intervals observed on-task increased from 78% ($SD = 19.1$) at pre-test to 99.3% ($SD = 1.91$) at post-test, $t(13)$

= -4.1, $p = .001$, $\eta^2 = .583$, while the Control Group mean increased from 77.4% (SD = 22.1) to 98.6% (SD = 2.15), $t\ (13) = -3.6$, $p = .003$, $\eta^2 = .519$.

2.3.4 Stability

A significant difference between groups was found for post-test rates of correct responding during stability timings, $F\ (1, 25) = 57.6$, $p < .001$, partial eta squared = .697. Paired samples t-tests showed a statistically significant increase in rate of correct responding for the Experimental Group from pre-test (M = 16.7, SD = 9.45) to post-test (M = 45.5, SD = 6.9), $t\ (13) = -13.6$, $p < .001$, $\eta^2 = .939$ and for the Control Group from pre-test (M = 15.7, SD = 10.4) to post-test (M = 28.8, SD = 7.08), $t\ (13) = -6.04$, $p < .001$, $\eta^2 = .752$. Again, both groups demonstrated significant improvements; however, those who had been exposed to frequency-building instruction were able to maintain a higher rate of correct responding in the presence of a distractor.

Percentage of intervals observed on-task increased across all participants during stability timings with no significant differences between groups at post-tests, $F\ (1, 25) = .141$, $p = .71$, partial eta squared = .006. The Experimental Group mean percentage of intervals observed on-task increased from 71.4% (SD = 29) at pre-test to 95.2% (SD = 4.78) at post-test, $t\ (13) = -3.19$, $p = .008$, $\eta^2 = .449$, while the Control Group mean increased from 64.7% (SD = 27.4) to 92.3% (SD = 19.2), $t\ (13) = -3.75$, $p = .002$, $\eta^2 = .54$. Table 2.4 shows the mean performances measures of stability at pre- and post-testing for both the Experimental and Control Group.

2.3.5 Application

No significant difference between groups was found for application post-tests, $F\ (1, 25) = 1.53$, $p = .227$, partial eta squared = .058. Paired samples t-tests for application timings showed a statistically significant increase in rate of correct responding from pre-tests ($M = 4.93$, $SD = 3.26$) to post-tests ($M = 13.8$, $SD = 4.86$), $t(13) = -7.94$, $p < .001$, $\eta^2 = .84$, for the Experimental Group and for the Control Group for pre-test ($M = 4$, $SD = 3.85$) to post-test ($M = 11.1$, $SD = 4.91$), $t(13) = -7.2$, $p < .001$, $\eta^2 = .812$. Table 2.4 shows the mean performances measures of application at pre- and post-testing for both the Experimental and Control Group. The Experimental Group's mean rates of correct responding increased marginally more than that of the Control Group.

2.3.6 Social Validity

Some 81% of participants within the Experimental Group responded that they would like to learn more mathematics problems using the frequency building intervention. All 14 participants responded that they learned their math facts well, remembered them better after the intervention and liked achieving their aims. Ninety percent responded that they liked practicing their mathematics as fast as they could with a timer and 82% responded that they were quicker with their maths. Forty-five percent of participants responded that they found it difficult to achieve their aims.

2.4 Discussion

Using a between group design, the current research demonstrated positive outcomes associated with a frequency-building intervention using the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum. Children between the ages of 9 and 11 years, identified as demonstrating difficulties performing at an age equivalent on the mainstream mathematics curriculum were successful in achieving fluency with component mathematic skills. Frequency-building also impacted standardised scores of Mathematical Reasoning (WIAT-II) indicating the advantages of learning component skills fluently in order to solve more complex problems. Outcomes associated with ability to attend as measured by rate of correct responding for prolonged timings and given conditions of distraction (i.e., endurance and stability) were also impacted. Participants' ability to apply those skills on measures of application was not affected.

All participants in the Experimental Group were placed at the beginning of the curriculum as no participant demonstrated fluency with any of the target skills prior to intervention. Subsequent to intervention, 71% of the participants had achieved 26 fluency aims of between 50-70 correct responses per minute. This implied achievement of fluency with 12 fact families and multiplying and dividing by 0 and 1. The remaining participants had achieved between 12-24 aims and were fluent with between five and 12 fact families. Further, participants in the Experimental Group scored significantly higher on measures of fluency at post-tests. Rate of correct responding increased significantly in comparison to the Control Group.

In a sample of 157 students in the fifth grade, Lin and Kubina (2005) found that only thirteen percent of participants achieved fluency for basic multiplication facts while 64% scored 100% accuracy. Similarly, the current research found dysfluent performances in multiplication and division for all participants during timed probes conducted to allocate the start point in the curriculum for each participant. Implementation of a frequency-building intervention was successful in building fluency with a number of multiplication and division skills. These findings are in accordance with previous research findings showing the efficacy of frequency-building to increase rates of correct responding in mathematics skills with primary school-aged children (Chiesa & Robertson, 2000; Gross et al., 2013; Hartnedy et al., 2005; Poncy et al., 2010).

The ability to maintain high rates of correct responding over increasing durations of responding and while in the presence of distractors was demonstrated by the Experimental Group. This supports assertions by proponents of fluency that individuals can maintain a steady performance for prolonged durations without fatiguing, and in the presence of environmental distractors (Binder et al., 1990; Fabrizio & Moors, 2003) when fluent with the relevant skills. Binder et al. (1990) suggest that endurance or “attention span” is a byproduct of behavioural fluency. When students become more accurate and fluent, they become capable of working steadily for longer durations (Binder et al., 1990). The current research supports this suggestion. Participants who had not received the frequency-building intervention did not achieve fluent responding in these conditions. Binder et al. (1990) argue that hesitant, dysfluent performance can be accompanied by an increase in error rates and negative emotional behaviours and that those students who lack fluency with component skills may be at greater risk of being diagnosed as having attentional deficits. The authors further suggest that in order to increase “attention span” or endurance, teachers should focus on building fluency.

In the current study, to assess participants’ ability to endure further, on-task behaviour was systematically observed using the BOSS during prolonged timings and timings with a distractor. No significant differences between groups were found. However, the Experimental Group showed significantly higher rates of responding than the Control Group for the same timings. Observing students’ physical topographies as a way of measuring “attention span” was not sensitive to the significant differences between groups in performance. This supports Binder et al. (1990) in their suggestion that “attention span” should be thought of in terms of performance rather than time on-task definitions. “Attention span” cannot be reliably defined in terms of on-task definitions only and should therefore include measures of performance (i.e., rate of correct responding on a given task).

Both groups showed a statistically significant increase in rates of correct responding for measures of application. The Experimental Group performed marginally better; however, there was no significant difference between the groups. As the intervention was implemented across a full school year, the improvement in scores demonstrated by both the Experimental and Control Group may have been attributable to their participation in treatment as usual mathematics classes. More complex mathematics problems were presented to each participant during the test for application which required the use of component skills beyond what were targeted in the frequency-building intervention. Such problems were likely practiced with both groups in mathematics classes throughout the year which may have contributed to the increases demonstrated by both groups.

Research in the area of behavioural fluency would suggest that experimental participants' scores on the test of application should have improved significantly more when compared with those who have not achieved fluency with component skills (Binder, 1996; Chiesa & Robertson, 2000). The automaticity of these skills should allow them to be more readily applied. Conversely, other researchers discuss the importance of practicing the application of fluent component skills rather than these automatically emerging once fluent (Codding et al., 2010; Martens & Witt, 2004). Codding et al. (2010) suggest that two types of practice exist consisting of drills and composite practice. Drills involve the practice of isolated items. Composite practice requires the use of learned component responses in combination with previously learned responses. It is possible that drill and composite practice each serve separate roles when building fluency with component skills (Codding et al., 2010) and may be equally as important. Increases on the Mathematical Reasoning subtest of the WIAT-II were found only for the Experimental Group. There was no change in score for the Control Group. Mathematical Reasoning is an orally presented verbal problem-solving test with pictures assessing ability to reason mathematically across a wide range of mathematical concepts (e.g., word problems, knowledge of measures and money, and mental rotation). Although results showed only a small effect size, frequency building implemented only once per week for 15-20 minutes had a significant impact on a standardised measure of Mathematical Reasoning indicating the value of teaching component skills fluently.

While composite mathematics scores on the WIAT-II were not significantly different at post-test, the Experimental Group' scores did increase marginally while the Control Group's scores decreased to a similar degree. This finding, in conjunction with the significant difference in Mathematical Reasoning scores, indicates that frequency-building instruction resulted in generalised effects as measured by the WIAT-II. Johnson and Street (2013) maintain that, within many educational settings, when students present with difficulties with a skill, supplemental teaching and a focus on that particular skill is the focus for remediation. Alternatively, using a generative instruction approach, dysfluent components of that skill are identified and taught to fluency criteria (Johnson & Street, 2013). Findings in the current study support the generative instruction approach. Participants who were presenting with difficulties performing at an age equivalent on the mainstream mathematics curriculum made significant gains when exposed to fluency-based instruction with component skills.

2.4.1 Limitations and Future Directions

Participants who did not achieve the target aims on successive weeks did not meet their terminal goal due to time constraints imposed by school holidays and the end of the school year. This may have been further impacted by the intensity of the intervention. The frequency-building intervention was implemented with the Experimental Group once per week for 15-20 minutes. Significant outcomes were found even as a result of what may be described as a low-intensity intervention; however, there were no increases in scores on the Numerical Operations subtest of the WIAT-II for either group and the difference in composite scores did not yield statistical significance. Further research is necessary to investigate intensity variables inclined to improve outcomes in this area. Chapter 5 within the current thesis focuses on the effects of fluency-based instruction in the context of varying levels of intensity.

Both subtests of the WIAT-II target a wide range of mathematical concepts and skills which required the use of many more component skills other than those targeted within this study. Further, only 26 aims from a possible 84 were selected and targeted as the terminal goal of intervention. Future research should also investigate the longitudinal impact of frequency-building with a number of component skills. Greater improvements in standard scores of mathematical ability may also be more obtainable with the implementation of an increased number of sessions per week or by increasing minutes of intervention.

The rate at which the Experimental Group achieved fluency aims varied across participants. Some attained the terminal goal (i.e., 26 aims) within 16 sessions while others did not reach the terminal goal (the lowest number of aims achieved was 12). There are a number of factors which could have accounted for the individual differences observed which were not specifically investigated in the current research. Low attendance and behavioural difficulties may have played a role in performance and achievement with some participants. Although these factors were not measured or targeted within the scope of the current study, such issues may need to be addressed through supplemental classroom management strategies that "fit" with the behavioural approach outlined herein.

Of the four participants that did not achieve all targeted fluency aims, composite scores on the WIAT-II ranged from 66 (extremely low) to 92 (average). Although the mean composite score for the entire Experimental Group was 87.71 (low average), the participant who achieved the least number of fluency aims overall fell into the extremely low category. Further, pre-tests scores of fluency (as measured by the review worksheet with targeted mathematics skills) were also lower for those four participants (between 3-11 correct responses per-minute) and fell below the mean pre-test fluency score for the Experimental Group. Mathematical ability and pre-test fluency potentially moderated the impact of the frequency-building intervention with those participants. This indicates that scores on standardised measures of mathematical ability and pre-test assessments of fluency with instructional materials could assist in predicting an individuals' ability to succeed with frequency building interventions. Chapter 4 within the current thesis investigates the moderating effects of such individual differences on frequency-building instruction.

2.4.2 Conclusion

Walker et al. (2013) suggest that children are exposed to multiple training tasks intended to improve learning of basic arithmetic skills and yet there is a paucity of experimental research investigating efficacy of such tasks. The authors indicate that children may be spending critical instructional time on tasks that have not been experimentally validated. The current research validates the use of the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum to increase fluency with children between the ages of 9 and 11 years identified as falling behind on an age appropriate mathematics curriculum. Positive outcomes were also demonstrated with respect to endurance, stability and standardised measures of mathematical ability.

Chapter 3 extends the current study to further evaluate fluency-based instruction using the Morningside Mathematics Fluency: Math Facts (Johnson, 2008) curricula within educational settings. It suggested that educators should focus more on improving accuracy and fluency in the early years (Carr & Alexeev, 2011) providing more opportunities to practice basic facts to facilitate fluent computation (Codding et al., 2010). Chapter 3 aims to examine fluency-based instruction in conjunction with the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) with participants in the first and second grade. The impact on associated critical outcomes and measures of standardised mathematical ability are further investigated with this sample of younger participants between the ages of 6-8 years.

Chapter 3:

Frequency-Building and Precision Teaching to Build Fluent Performances with Mathematics Skills

3.1 Introduction

Chapter 2 evaluated the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum to teach component mathematics skills to fourth and fifth grade students receiving daily remedial support in mathematics. The Experimental Group demonstrated significant increases in rate of correct responding with targeted mathematics skills, as well as significantly larger scores on the ability to endure for longer durations and with distractions, as compared with the Control Group. Increases on standardised measures of mathematical ability were also found only for the group who received intervention. The current study evaluated the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum in order to add to the literature on empirical validation of curricula designed to increase fluency with component mathematics skills and to facilitate decision making in educational settings regarding the efficacy of such curricula.

Similar to Chapter 2, frequency-building sessions were implemented using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum. In addition to this, Precision Teaching (PT) was used to evaluate students' performance throughout the intervention. PT has been described as a general approach that can determine whether an instructional method is achieving its aims (Chiesa & Robertson, 2000). It achieves this by monitoring and evaluating progress to facilitate decision-making on instruction based on data displayed on Standard Celeration Charts (SCC). Hughes et al. (2007) assert that the addition of PT in educational settings helps to ensure that every child in a class is learning successfully. Findings in Chapter 2 demonstrated that 29% of participants did not achieve their terminal goal of 26 fluency aims (those who didn't achieve 26 aims achieved between 12-24 aims). Considering the purported advantages of using PT to monitor students' progress, the current study included this method of evaluation to record daily rates of correct responding, observe performances on SCC's and inform decision-making regarding instruction.

The importance of achieving fluency with component mathematics skills is emphasised in Chapter 2 and findings of the study confirm significant outcomes resulting from fluent performances. Chapter 2 focused on students who were failing to keep pace with their peers in order to remediate mathematics difficulties and understand its impact on measures of mathematical ability. Considering the prevalence of mathematics skills deficiencies, such research is necessary to identify educational treatments for "at-risk" students but also at a classroom level to improve performances for all students (Codding et al., 2009; Poncy et al., 2013). Johnson and Street (2013) argue that educators may prevent academic failure by providing comprehensive and evidence-based programs for all students and the level of support needed to ensure normative progress. The current study evaluated frequency-building using PT and the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum with students within first and second grade in a mainstream school, without a pre-specified criterion for inclusion of those who were experiencing difficulties with the mainstream mathematics curriculum.

Chapter 2 used between-group analyses to identify significant differences between an Experimental Group who received intervention and a treatment-as-usual (TAU) Control Group. The current study also employed between-group analyses. However, in order to counteract difficulties arising from recruitment of participants to a TAU control condition (e.g., recruiting participants from a school on the basis that only some of the students within classes will receive the intervention but all must take part in assessments at pre- and post-testing), this study applied intervention to two groups across two different academic domains. Frequency-building using PT was implemented with both groups; however, one group received intervention to increase fluency with mathematics skills and the second group who represented a “control” group, received intervention with component reading skills using the Morningside Phonics Fluency: Basic Elements (Johnson et al., 2005) curriculum.

Although research evaluating instructional approaches has focused more on reading than on mathematics(Burns et al., 2006; Codding et al., 2009), there remains a need for research investigating instructional programs designed to build reading fluency (Chard, Vaughn, & Tyler, 2002; Codding et al., 2009; Thaler, Ebner, Wimmer & Landerl, 2004). Research has determined that fluency is one of the most essential components of proficient reading (Calhoon & Petscher, 2013; Silber & Martens, 2010) and should be a key component of early elementary reading instruction (Begeny, Krouse, Ross & Mitchell, 2009; Begeny et al., 2012). Jenkins, Zumeta, Dupree and Johnson (2005) maintain that the speed with which individuals are able to reproduce text into spoken language is one of the most salient characteristics of skilled reading and that oral reading fluency as an indicator of overall reading competence has both strong theoretical and empirical backing. The reading curriculum implemented within the current study is designed to increase accuracy and fluency with word identification skills and includes pre-determined fluency aims for each targeted component skill.

As in Chapter 2, measures of outcomes associated with fluency were assessed with both groups pre- and post-intervention, namely endurance and application. Increases in rate of correct responding with targeted skills were monitored for each participant on SCC’s throughout the intervention. The impact of building fluency with component skills was again evaluated using standardised measures of mathematical and reading ability. The Woodcock Johnson, Third Edition (WJIII; Woodcock, McGrew, & Mather, 2001b) provides standardised norm-referenced measures of academic abilities. Included in this assessment were subtests of mathematics and reading fluency. For this reason, it was used in place of the WIAT-II which uses similar subtests but without measures of fluency with academic skills.

3.2 Method

3.2.1 Participants and Setting

Participants were 42 typically developing students in first and second grade with a mean age of 7 years and 5 months (SD = .64, range: 6.5 – 8.9). Fifty-three participants were initially recruited to take part. However, due to a high level of absenteeism and the inability of a number of participants to access the curricula, 11 participants were unable to continue with intervention or did not meet the required number of sessions to be included in the study. All of the participants attended a mainstream school located in a disadvantaged community, qualifying for participation in a School Support Programme (Delivering Equality of Opportunity in Schools; DEIS) by the Department of Education (DES, 2005). Twelve were male (29%) and 30 were female (71%). Mean scores for the entire sample on mathematical and reading fluency, assessed using the WJIII, were 102 (SD = 12.58, range: 75 – 145) for mathematics fluency and 103 (SD = 12.72, range: 70 – 131) for reading fluency indicating that the sample's mean standard scores for both reading and mathematics fell within the average range (90 – 110) for both assessments. Parental consent was obtained for all participants included in the study.

The intervention took place during school hours with four to six participants in each session and between two and four instructors. Sessions were conducted in the same classroom each week with all participants sitting around a table with their materials on the desk in front of them.

3.2.2 Materials

Each participant was allocated a folder containing materials for frequency-building and PT. Participants were provided with data collection sheets to record the number of correct and incorrect responses they had achieved after each timing (see Appendix E). The data collection sheet included the fluency aim for each worksheet, the date, space to input correct and incorrect responses and a prompt for each participant to request a raffle ticket once they achieved their aim. Worksheets currently being practiced and SCC's were also located in each participant's folder. Digital timers were used to conduct timings.

3.2.2.1 Curricula

The Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum was used to teach component mathematics skills. This curriculum is designed to build fluency with addition and subtraction computation (using fact families) and is structured in the same manner as the multiplication and division curriculum used in Chapter 2 (samples of worksheets from the curriculum are included in Appendix F.

The Morningside Phonics Fluency: Basic Elements (Johnson et al., 2005) curriculum was used to teach component reading skills. This curriculum teaches word identification skills using nonsense words targeting skills needed to sound out words rather than reliance on previous sight word training. A total of 56 "slices" target different combinations of vowels, consonants, word endings, diphthongs and blends including consonant-vowel sounds (CV; e.g., "se", "ku", and "vi"), consonant-vowel-consonant sounds with endings (CVC + endings; e.g., "poms", "seppy" and "ough") and elements (e.g., "tough", "though", and "thorough"). Each slice consists of four worksheets which contain 100 nonsense words. Words are read from left to right across the worksheet until a fluency aim of 80-100 words read per minute is achieved for each slice (samples of worksheets from the curriculum are included in Appendix G).

3.2.3 Design

A between-group alternative treatment design was used to evaluate the effects of frequency-building using PT and each curriculum on dependent measures. Participants were randomly assigned to either the Mathematics Group (n=24) or the Reading Group (n=18). Twenty-seven participants were initially assigned to the Mathematics Group and 26 assigned to the Reading Group; however, 11 participants were unable to continue with the intervention or did not receive the minimum number of sessions required to be included in the study due to absenteeism.

Measures of mathematical and reading ability were conducted with all participants pre-intervention. Those in the Mathematics Group were subsequently exposed to frequency-building using PT and Morningside Math Facts: Addition and Subtraction (Johnson, 2008) and received TAU on reading instruction. Those in the Reading Group were exposed to frequency-building using PT and Morningside Phonics Fluency: Basic Elements (Johnson et al., 2005) and received TAU on mathematics instruction. Each group represented both an Experimental and a Control Group for either the reading or mathematics conditions. Once each participant had received 22 intervention sessions, the same measures of mathematical and reading ability were conducted post-intervention with all participants. This was to evaluate whether those who had received intervention with mathematics skills would achieve higher scores on post-test measures of mathematical ability, and if participants who had received intervention with reading skills would achieve higher scores on reading measures at post-test.

3.2.4 Dependent Measures

The effects of each intervention were investigated in relation to scores on mathematics and reading subtests of the WJIII, Pseudoword Decoding (WIAT-II; Wechsler, 2005), measures of application for mathematics (Morningside Mathematics Fluency: Whole Number Computation; Johnson & Melroe, 2006) and reading (Oral Reading Fluency, DIBELS; Good & Kaminski, 2002) and measures of endurance. Rate of correct responding was recorded and monitored daily using SCCs.

3.2.4.1 WJIII

The WJIII provides norm-referenced measures of academic abilities. Subtests measure abilities across mathematics, reading, writing, oral language abilities and academic knowledge. Subtests for mathematics and reading were conducted with both groups pre- and post-intervention.

3.2.4.1.1 Applied Problems

The Applied Problems subtest measures quantitative reasoning, mathematics achievement and knowledge. Word problems are presented orally in conjunction with using the stimulus booklet which represents problems using pictures and, at the more difficult levels, words. As the problems increase in difficulty participants are provided with a paper and pencil to use to find the answer.

3.2.4.1.2 Calculation

Calculation measures math achievement in relation to ability to access and apply knowledge of numbers and calculation procedures. It is a paper and pencil test involving arithmetic and computation. Participants were presented with the problems on a worksheet and provided written answers on the sheet next to each problem.

3.2.4.1.3 Mathematics Fluency

The fluency subtest measures mathematics achievement; specifically, the ability to access and apply automatically, and with speed, digit-symbol arithmetic procedures. Participants were presented with a sheet of simple calculations and asked to answer as many as they could correctly in three minutes. The subtest includes two sheets in total with 80 calculations on each.

3.2.4.1.4 Letter-Word Identification

The Letter-Word Identification sub-test measures reading decoding. Participants were asked to name letters and read words aloud from a list.

3.2.4.1.5 Passage Comprehension

Participants' reading comprehension was measured using the Passage Comprehension sub-test. Participants were required to identify what the missing word was that was removed from a number of sentences or brief paragraphs (e.g., "That soup is too hot to ___").

3.2.4.1.6 Reading Fluency

The Reading Fluency subtest was conducted to measure speed of reading. Participants were required to read sentences as quickly as they could and answer "yes" or "no" to indicate if the sentence represented a true or false statement. Typed sentences were presented on a sheet with 40 statements followed by the yes/no option. Each sentence is read and a circle drawn around participants' chosen response.

3.2.4.2 Fluency

Rate of correct responding was recorded to evaluate participants' fluency with target mathematics and reading skills. For mathematics worksheets, a correct response was recorded if all digits in the answer to the problem were correct. Responses were scored as incorrect if any digits in the answer to a problem were incorrect, if digits were omitted or placed in the incorrect order. For reading worksheets, responses were scored as incorrect if any component of the word was read incorrectly (e.g., vowel, consonant, ending), if the word was omitted or if any component of the word was omitted. Correct responses were recorded when each component of the word was read correctly.

For both the Mathematics and Reading Group, both Timings Charts and Daily Per Minute Charts (SCCs) were used to record rates of correct and incorrect responding. Timings Charts permit the recording of rate of correct and incorrect responding for each timing and were included to collect within-session data. Daily Per Minute Charts are used to record one data point for each day in order to monitor progress across sessions. For this reason, they were also included in the current study to record participants' highest rate of correct responding each day and monitor progress across sessions.

3.2.4.3 Application Mathematics

The Morningside Whole Number Computation: Addition and Subtraction (Johnson & Melroe, 2006) curriculum was used as a measure of participants' ability to apply mathematics skills to more complex skills of column addition and subtraction with renaming, both accurately and fluently (samples of worksheets from the curriculum are included in Appendix H). The curriculum is synchronised with the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum which was used during intervention sessions. This meant that participants were tested with items requiring math facts which had been targeted during intervention.

Worksheets contained either subtraction problems requiring renaming or addition problems requiring column addition. Each sheet contained 25 problems with varying numbers of columns within each. Participants were given two minutes for both a subtraction and an addition worksheet to complete as many problems as they could correctly. Digits correct per minute (DCM) was calculated in order to determine rate of correct responding. Each correct digit within an answer was scored as correct if it was placed in the correct position in the answer. Digits were scored as incorrect if an incorrect digit was written, if it was incorrectly placed in the answer or if it was omitted. Percentage of digits correct was also calculated and evaluated for this measure.

3.2.4.4 Application Reading

The Dynamic Indicators of Basic Early Literacy Skills (DIBELS; Good & Kaminski, 2002) test of Oral Reading Fluency (ORF) was used as a measure of participants' ability to apply reading skills acquired to fluency, to reading connected text, both accurately and fluently. This is a standardised, individually administered set of reading passages with administration procedures calibrated for each grade level (samples of reading passages used are included in Appendix I). Performance is measured by having participants read a passage aloud for one minute while recording omitted words, substituted words and errors. Errors are recorded if the student hesitates for more than three seconds. A self-correction within three seconds is scored as correct. The ORF score is calculated by the number of correct words read per minute. Percentage of words read correctly was also calculated and evaluated for this measure.

3.2.4.5 Pseudoword Decoding

The Pseudoword Decoding subtest of the WIAT-II measures the ability to apply phonetic decoding skills and determines whether the phonological decoding mechanism is developing at an age-appropriate manner. A list of nonsense words is read aloud by participants to the examiner. Words are read from an A4 card from left to right while the examiner records correct and incorrect responses. The words are designed to be representative of the phonetic structure of words in the English language.

3.2.4.6 Endurance

Similar to Chapter 2, the ability to sustain a steady performance over an increased duration of time was evaluated. Measures of endurance were implemented for both mathematics and reading skills. During endurance tests for mathematics, participants completed as many problems as they could, using pencil and paper worksheets during an extended 5-minute timing. All problems required one or two digit answers and had been targeted during the intervention. These were later scored by the experimenter and rate of correct responding per minute was calculated. Correct and incorrect responses were scored using the same definitions applied for calculating fluency with target skills within sessions.

During endurance tests for reading, participants read as many words as they could to the examiner during an extended 5-minute timing. Presented words were those that were targeted during the intervention. The examiner scored correct and incorrect responses during the timing and rate of correct responding was later calculated. Correct and incorrect responses were scored using the same definitions applied for calculating fluency with target skills within sessions.

3.2.5 Procedure

3.2.5.1 General Procedures

Participants were exposed to either the mathematics or reading interventions for 22 sessions conducted over 13 to 15 weeks. Sessions were between 15-20 minutes in duration and took place three days per week. There were four to six participants in each group and two to four instructors per group. Instructors included the experimenter and four Masters level students completing university postgraduate training in Applied Behaviour Analysis. Group training sessions in frequency-building, PT and use of the curriculum were provided by the experimenter for instructors prior to and throughout the course of the school year. The experimenter was also on-site and provided individual on-site training and feedback on instructors' implementation of the intervention. Fluency aims (i.e., target number of correct responses per minute) were pre-determined by each curriculum for each skill. Post-tests were conducted with each participant once they had received 22 intervention sessions.

3.2.5.2 Curriculum Start Point Allocation

Once pre-tests were completed and each participant had been randomly assigned to a group, they were placed on the relevant curriculum (i.e., mathematics or reading). This involved exposing each participant to 1-minute timed probes with worksheets from different levels of the curriculum. Participants were placed at the point at which they did not achieve the fluency aims outlined by the specific curriculum. As no participant attained fluency aims on any level of either of the curricula, all were allocated start points at the beginning of the instructional material.

3.2.5.3 Frequency-Building Sessions

During the first session, folders were allocated and the general procedure was explained to both groups. Participants were shown how and where to record correct and incorrect responses after timings, how to identify what slice of the curriculum or worksheet they should be working on and the corresponding fluency aim. It was explained to each participant that they would receive "checks" based on four target behaviours. The first target behaviour was "working well" and checks were delivered contingent on correct responding and working independently. The second target behaviour was "working fast" and checks were received in this category if participants beat their score on their previous timing. The third target behaviour was "getting your goal" and participants received a check in this category for achieving a fluency aim. Lastly, participants received checks for "good listening" whereby checks were awarded when participants listened to, and followed instructions, throughout the session.

Each participant had a chart (see Appendix J) on the desk beside their folder with pictures and words representing each category. The instructor reinforced target behaviours throughout the session by simply placing a check on the relevant category. Once five checks were accumulated, a raffle ticket was awarded. If ten checks were achieved within one session, two raffle tickets were awarded. One check on the "getting your goal" category was immediately reinforced with a raffle ticket ensuring that achieving a fluency aim received a higher magnitude of reinforcement. At the end of each week, the raffle was conducted and one participant chose an item from the "prize box".

3.2.5.3.1 Mathematics Group

The Mathematics Group was subdivided into smaller groups for instructional purposes. Each subdivided group consisted of five or six participants and between two and four instructors. Groups were scheduled to receive frequency-building instruction at differing times during the school day so that each group received intervention at the same time each day.

Before participants began Explicit Timing (ET) with each pencil and paper worksheet, they were required to learn each fact family orally. It was explained that they should practice reciting each as fast as they could and they were informed of their fluency aim (4-6 seconds). An instructor would return to the participant after a period of time and verify that each family could be recited in 4-6 seconds. The participants recorded their correct and incorrect responses on the data collection sheet following each timing.

When participants were completing pencil and paper worksheets they marked an X on the worksheet to indicate how many problems they would need to complete to beat their score from their previous timing. The instructors circulated amongst the participants to ensure everyone in the group was working on the correct target and had identified the correct fluency aim. When the group was ready, a timing was started. Each participant was asked to place their pencil on the paper at their start point. They were reminded that they needed to answer as many problems as they could correctly in one minute and should try to beat their score from the last timing. They were also made aware of the fluency aim allocated to the worksheet which they would need to achieve in order to obtain a raffle ticket and to move on to the next worksheet. The instructor set the timer for one minute, said, “Let’s begin”, and started the timer.

3.2.5.3.2 Reading Group

The Reading Group was also subdivided into smaller groups for instructional purposes. Each subdivided group consisted of four or five participants and between two and four instructors and similar to the Mathematics Groups, were scheduled to receive frequency-building instruction at differing times during the school day.

Each participant was presented with a laminated copy of the worksheet that they were currently working on. Instructors conducted 1-minute timings on a one-to-one basis with each participant. The participant was reminded where to start on the worksheet, that they should read as many words as they could correctly for one minute and try to beat their scores from their last timing. They were also reminded of the fluency aim allocated to the worksheet which they would need to achieve to obtain a raffle ticket and to move on to the next worksheet. The timer was set for one minute and the participant began reading on the signal, “Let’s begin”. The instructor held a copy of the worksheet in order to record correct and incorrect responses as the participant read the words aloud. Correct responses were not marked while incorrect responses were circled allowing for corrective feedback to be provided between timings. Participants recorded their correct and incorrect responses on the data collection sheet following each timing.

3.2.5.3.3 Corrective Feedback

No corrective feedback was delivered during timings; however, participants received praise throughout timings contingent only on active engagement in the task. During mathematics sessions, when a timing was complete, the group was instructed to “drop their pencils”, count the number of problems they had completed and to signify any incorrect responses by drawing a circle around it. The instructors circulated amongst the group to verify number of correct and incorrect responses and to provide corrective feedback on errors with participants individually. The instructor identified incorrect responses and presented the relevant problems orally. Least-to-most prompts were used until the participant could emit the correct response.

During reading sessions, when a timing was complete, the instructor placed a line on the recording sheet next to the last word read aloud by the participant. Corrective feedback was provided using the recording sheet. The instructor targeted any words which had been read incorrectly and used least-to-most prompts until the participant could read the word correctly.

During both mathematics and reading sessions, when a participant achieved a fluency aim they received a check for “getting your goal” and a raffle ticket. If a fluency aim was not achieved but faster rates of responding were obtained, the participant received a check for “working fast”. When participants had increased correct responding they received a check for “working well”. When a fluency aim was not attained, additional ET was subsequently implemented until the fluency aim was achieved.

3.2.5.3.4 Decision Analysis

Decisions about each participant’s progress were made by assessing their SCCs. Timings Charts were completed during the session facilitating decisions on progress within each session. Daily Per Minute Charts were also completed in order to make decisions based on progress across sessions. Each participant’s “learning picture” was assessed on both charts in order to decide how to progress with instruction. When participants demonstrated a steady increase in rate of correct responding, they continued with ET and corrective feedback until the fluency aim for each worksheet was achieved.

Aspects of teaching were adapted based on learning problems demonstrated on the SCCs. If a participant's performance was accurate but low in frequency adaptations were made in order to build frequency. The adaptations always matched the difficulty each participant presented with. For example, the number of opportunities for timings was increased and less time given to corrective feedback, the number of checks contingent on higher rates of correct responding (i.e., beating scores from previous timings) was increased, sprints involving 10-15 second timings were implemented to allow the participant to obtain reinforcement contingent on faster rates of responding (with timings gradually increased back to one minute) and changes were made to the environment to ensure no ceilings were inhibiting participants from achieving higher rates of correct responding.

If participants' learning pictures demonstrated a high rate of errors, adaptations to teaching were made to ensure the skill was acquired accurately. In this way the intervention always matched the difficulty presented. For example, skills on which errors were made consistently were isolated, untimed practice with corrective feedback was provided after each response and rate of correct responding increased with the isolated set before returning to the original worksheet. For some participants an accuracy criterion was set for the instructional material which was met before returning to ET.

When rate of correct responding was variable and compliance was observed to be a problem within a session, participants were reminded that reinforcement was contingent on the four previously named target behaviours. Instructions were increased to provide greater opportunity to reinforce "good listening" and participants observed to work throughout timings without distraction received checks for "working well".

3.3 Results

Each participant received 22 sessions, 15-20 minutes in duration, of frequency-building instruction using PT and either the mathematics or reading curriculum. Fluency with target skills was recorded and evaluated daily using SCCs. One-way between-group analyses of covariance (ANCOVA) were conducted to compare post-test scores on the remaining dependent variables and to evaluate the effectiveness of each intervention. Between-group differences were investigated to determine if participants who had received intervention for mathematics scored significantly higher at post-test on mathematics measures, than those who received TAU on mathematics but received intervention with reading skills. The effects of the reading intervention were evaluated in a similar manner. Scores obtained on reading assessments were compared to determine if those in the reading group scored significantly higher at post-test on reading measures than those who received TAU on reading instruction but received instruction on mathematics.

Participants' pre-test scores were used as covariates in the analyses. Preliminary checks were conducted for each ANCOVA to ensure that there was no violation of assumptions. A correction to control for multiple testing was not included in statistical analyses since it is recommended that corrections be used when investigators are searching for significant relationships but without pre-established hypotheses (Armstrong, 2014; Perneger, 1998). The current research investigated specific hypotheses outlined prior to data collection and statistical analyses. Paired samples t-tests were conducted for both the Mathematics and Reading Groups' pre- and post-test scores to examine increases in scores on dependent variables within each group. For statistical analysis, only those participants who achieved two fluency aims or more were included. This meant that seven participants (i.e., Participants 19, 20, 21 and 23 in the Mathematics Group and Participants 28, 35 and 37 in the Reading Group) were excluded from the analyses.

3.3.1 Fluency

Fluency aims ranged from 50-70 correct responses per minute across mathematics worksheets and were always 80-100 words read correctly per minute for each slice in the reading curriculum. As shown in Table 3.1, the achievement of fluency aims varied across participants within each group. Over the 22 sessions, the Mathematics Group achieved a mean of 3.6 fluency aims ranging from zero to 15. The Reading Group were exposed to the same intensity (i.e., 22 sessions) of instruction and achieved a mean of 2.9 aims ranging from zero to nine.

Participant (Math Group)	Number of fluency aims achieved	Participant (Reading Group)	Number of fluency aims achieved
1	6	25	2
2	2	26	3
3	3	27	3
4	11	28	1
5	3	29	2
6	13	30	3
7	3	31	3
8	3	32	3
9	3	33	3
10	3	34	3
11	2	35	0
12	2	36	9
13	2	37	1
14	2	38	4
15	2	39	4
16	3	40	2
17	2	41	4
18	2	42	3
19	1		
20	0		
21	1		
22	15		
23	0		
24	3		

Table 3.1 Number of fluency aims achieved by participants in both the Mathematics and Reading groups.

Daily Per Minute Charts for Participants 4 and 20 in the Mathematics Group are shown in Figures 1 and 2 and show the variability in number of fluency aims achieved across participants. Figure 1 shows the Daily Per Minute Chart for Participant 4 who achieved 11 fluency aims. Figure 2 shows the Daily Per Minute Chart for Participant 20 who did not achieve any fluency aims as outlined by the curriculum; however, an increase in rate of correct responding was achieved. Participant 20 was moved to the next worksheet in the curriculum, before achieving the pre-determined fluency aim, as she had achieved a rate of correct responding which was close to the pre-determined fluency aim.

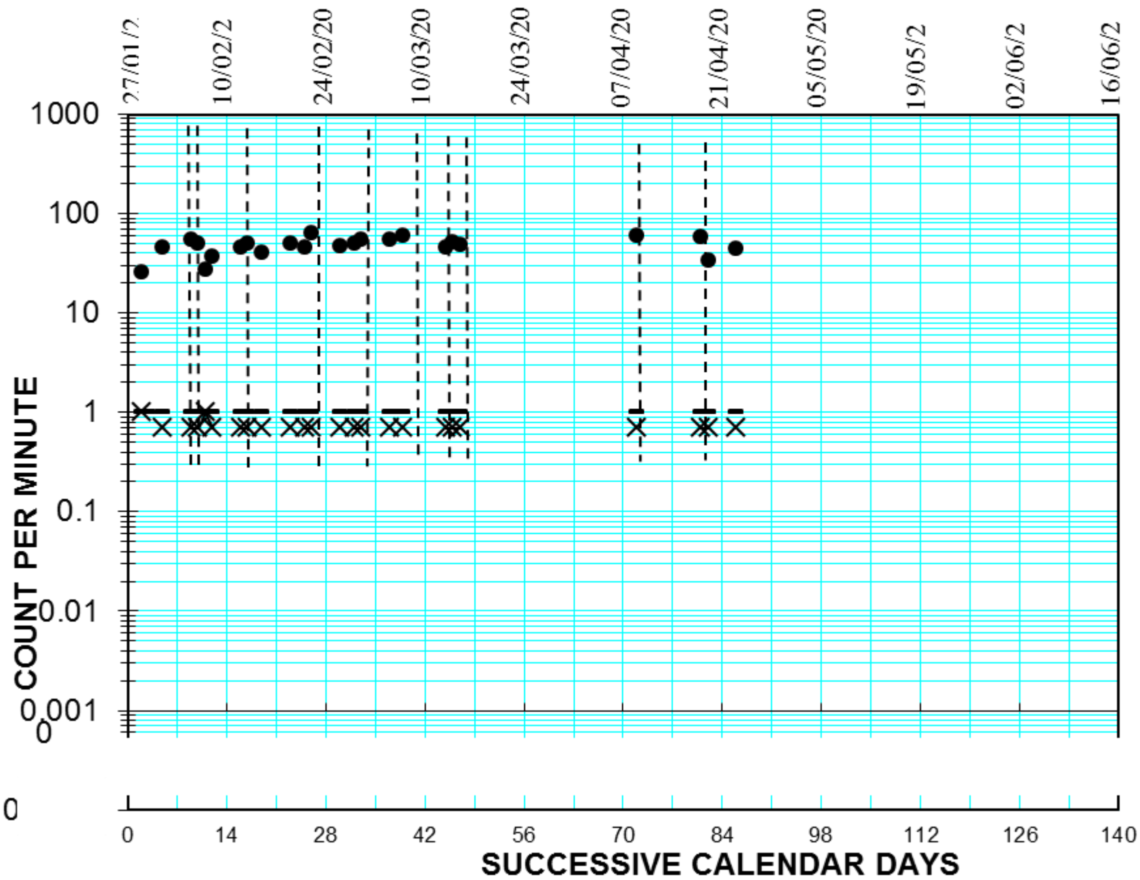

Figure 1. Daily Per Minute SCC showing the best daily scores in mathematics skills for Participant 4.
**Note. Phase-lines indicate progression to next fluency aim.*

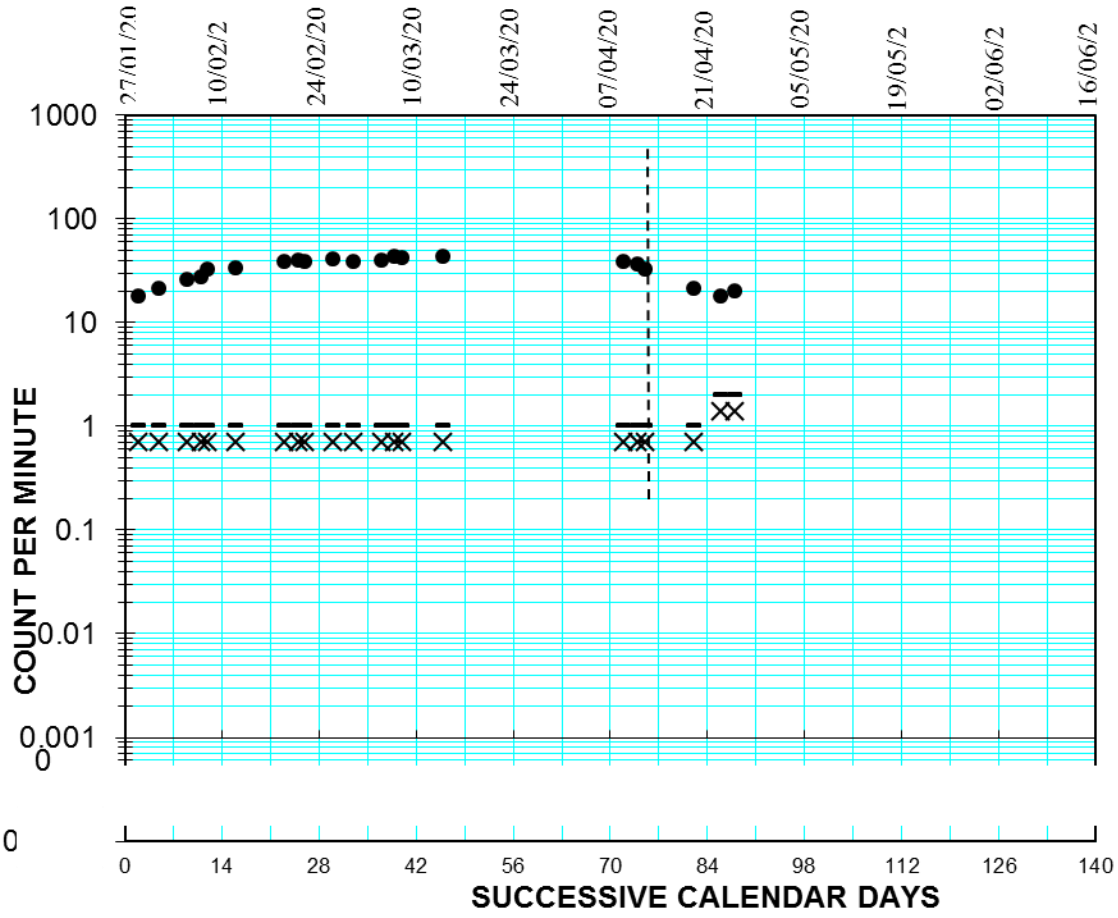

Figure 2. Daily Per Minute SCC showing the best daily scores in mathematics skills for Participant 20.
**Note. Phase-lines indicate progression to next fluency aim*

Daily Per Minute Charts for Participants 39 and 37 in the Reading Group are shown in Figures 3 and 4 and show the variability in number of fluency aims achieved across participants in the Reading Group. Figure 3 shows the Daily Per Minute Chart for Participant 39 who achieved four fluency aims. Figure 4 shows the Daily Per Minute Chart for Participant 37 who achieved only one fluency aim; however, an increase in rate of correct responding across sessions was demonstrated.

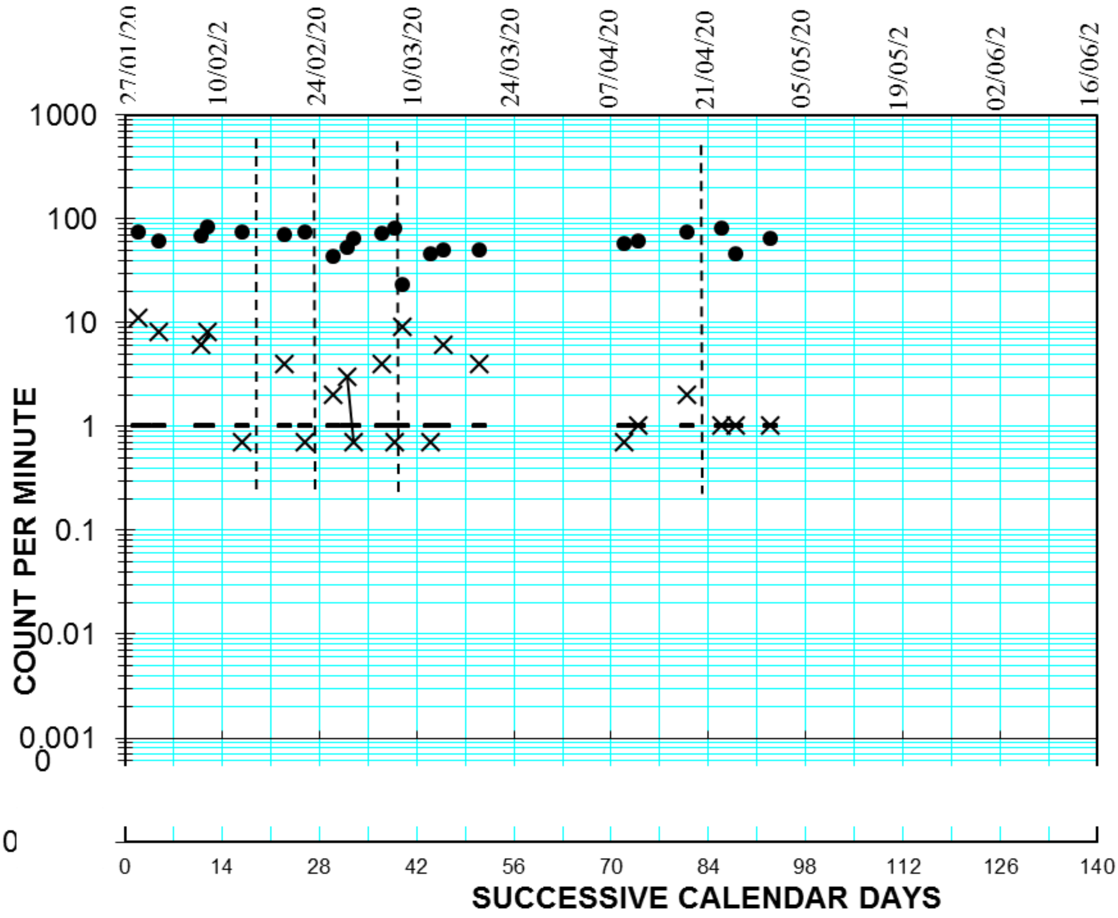

Figure 3. Daily Per Minute SCC showing the best daily scores in reading skills for Participant 39.
**Note. Phase-lines indicate progression to next fluency aim*

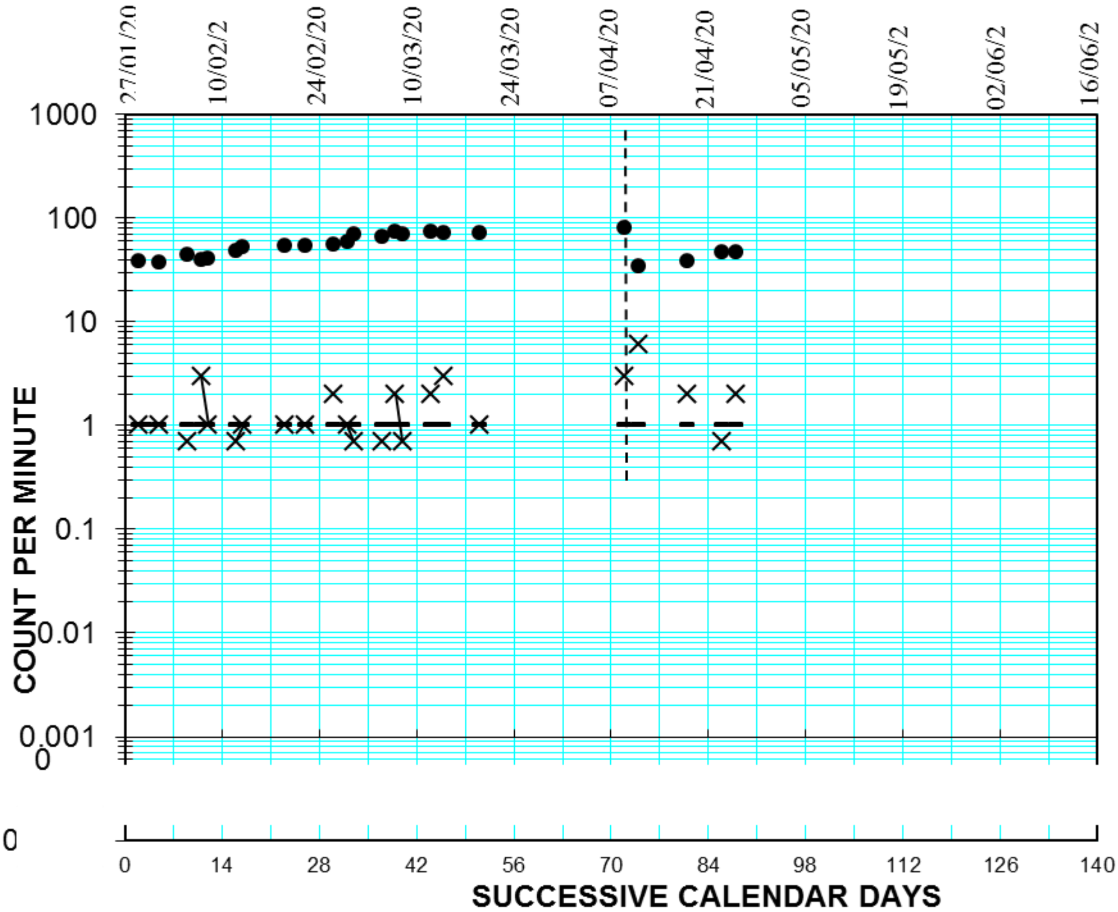

Figure 4. Daily Per Minute SCC showing the best daily scores in reading skills for Participant 37.
**Note. Phase-lines indicate progression to next fluency aim*

3.3.2 Mathematics Group Outcomes

3.3.2.1 Standardised Measures of Mathematical Ability

After adjusting for pre-intervention scores, there were no significant differences between the two groups on post-intervention scores on the Applied Problems, Calculation and Mathematics Fluency subtests of the WJIII. Table 3.2 shows the adjusted mean post-test scores for each subtest. Results of t-tests conducted to investigate changes in scores on the Applied Problems and Calculation subtests of the WJIII from pre- to post-test demonstrated no significant changes in scores for either group. There was a statistically significant increase in scores on the Mathematics Fluency subtest for the Mathematics Group from pre-test ($M = 106.65$, SD = 10.8) to post-test (M = 112.41, SD = 13.52), t (16) = -2.147, p < .05. The eta squared statistic (.24) indicated a large effect size. There was no significant increase for the Reading Group from pre-test (M = 101.92, SD = 8.06) to post-test (M = 104.14, SD = 8.07), t (13) = -.841, p = .415.

	Mathematics Group			Reading Group		
DV	N	M	Std. Error	N	M	Std. Error
Applied Problems	19	98.5	2.52	12	102.4	3.17
Calculation	11	102.5	2.89	13	96.8	2.66
Math Fluency	17	111.1	2.46	14	105.7	2.71
Endurance Mathematics	17	23.8	1.24	12	16.7	1.49
Application Addition (Rate)	14	12.2	.89	12	9.5	.96
Application Addition (% correct)	14	98.5	1.14	12	93.6	1.22
Application Subtraction (Rate)	15	17.7	1.62	13	12.5	1.75
Application Subtraction (% correct)	15	95	1.89	13	93	2.03

Table 3.2 Adjusted mean post-test scores for mathematics dependent measures

3.3.2.2 Critical Learning Outcomes

One-way between-group analyses of covariance were conducted to investigate the impact of the mathematics intervention on participants' ability to endure for longer durations as measured by rate of correct responding during prolonged timings. After adjusting for pre-intervention scores there was a significant difference between the two groups on post-intervention measures of endurance with mathematics skills, F (1, 26) = 12.74, p < .005, partial eta squared = .329. The Mathematics Group scored significantly higher on the mathematics endurance test. Table 3.2 shows adjusted mean post-test scores for measures of endurance with mathematics skills.

Rate of correct responding on the endurance test increased significantly for the Mathematics Group from pre-test ($M = 15.01$, $SD = 6.54$) to post-test ($M = 25.76$, $SD = 12.24$), $t(16) = -6.055$, $p < .001$. The eta squared statistic (.7) indicated a large effect size. The Reading Group also demonstrated an increase in scores from pre-test ($M = 12.02$, $SD = 2.68$) to post-test ($M = 13.92$, $SD = 4.56$), $t(11) = -2.455$, $p < .05$. However, the eta squared statistic (.3) indicated a smaller effect size.

There was a significant difference between groups on post-intervention rates of correct responding on tests of application using subtraction after adjusting for pre-intervention scores, $F(1, 25) = 4.5$, $p < .05$, partial eta squared = .152. Post-test scores were higher in the Mathematics Groups compared to those in the Reading Group. Rate of correct responding on the test of application using subtraction increased significantly for the Mathematics Group but not for the Reading Group. The Mathematics Group's scores increased from pre-test ($M = 11.73$, $SD = 8.19$) to post-test ($M = 18.87$, $SD = 9.77$), $t(14) = -3.828$, $p < .005$. The eta squared statistic (.53) indicated a large effect size. There were no statistically significant increases in mean percentage correct scores on measures of application using subtraction for either group.

There was no significant difference in post-test rates of correct responding between groups for tests of application using addition, $F(1, 23) = 3.95$, $p = .059$, partial eta squared = .15. Rate of correct responding on the test of application using addition significantly increased for the Mathematics Group from pre-test ($M = 8.92$, $SD = 5.69$) to post-test ($M = 13.07$, $SD = 5.17$), $t(13) = -4.047$, $p = .001$. The eta squared statistic (.57) indicated a large effect. There was also an increase for the Reading Group from pre-test ($M = 5.5$, $SD = 3.7$) to post-test ($M = 8.5$, $SD = 2.42$), $t(11) = -2.704$, $p < .05$. The eta squared statistic (.42) indicated a smaller effect size.

A statistically significant difference between groups was found for percentage correct scores on measures of application using addition, $F(1, 25) = 8.21$, $p < .01$, partial eta squared = .25. Mean percentage correct scores on application using addition increased significantly for both the Mathematics Group ($t(14) = 2.33$, $p < .05$) and the Reading Group ($t(12) = 2.61$, $p < .05$). Table 3.2 shows adjusted mean post-test scores for measures of application with mathematics skills.

3.3.3 Reading Group Outcomes

3.3.3.1 Standardised Measures of Reading Ability

One-way between-group analyses of covariance were conducted for post-test scores on Letter-Word Identification, Passage Comprehension and Reading Fluency subtests of the WJIII. After adjusting for pre-intervention scores, there were no significant differences between groups on post-test scores across all three subtests. Results of t-tests evaluating changes in mean scores from pre- to post-test demonstrated no significant change in scores for either group on the same measures.

	Mathematics Group			Reading Group		
DV	N	M	Std. Error	N	M	Std. Error
Pseudoword Decoding	16	98.9	2.65	14	98.7	2.85
L-W Identification	16	110.5	1.26	15	111.1	1.3
Passage Comp	15	98.9	1.5	13	101.4	1.62
Reading Fluency	13	108.9	2.3	15	107.4	2.14
Endurance reading	15	39.38	2.46	11	48.3	2.94
Application Reading (Rate)	15	93.3	6.09	14	104.3	6.32
Application Reading (% correct)	15	97.3	.568	14	98.2	.637

Table 3.3 Adjusted mean post-test scores for reading dependent measures

No significant differences between groups were found for post-test scores on the Pseudoword Decoding subtest of the WIAT-II and there was no statistically significant increase on this measure for either group. However, the Reading Group's scores did increase more than that of the Mathematics Group from pre-test ($M = 88.5$, $SD = 10.65$) to post-test ($M = 94.78$, $SD = 12.84$) and this increase was close to statistical significance ($p = .060$). Table 3.3 shows post-test adjusted mean scores on standardised measures of reading ability.

3.3.3.2 Critical Learning Outcomes

One-way between-group analyses of covariance were conducted to investigate the impact of the reading intervention on participants' ability to endure for longer durations as measured by rate of correct responding during prolonged timings. After adjusting for pre-intervention scores there was a significant difference between groups on post-intervention measures of endurance with reading skills, $F(1, 23) = 4.71$, $p < .05$, partial eta squared = .17. The Reading Group scored significantly higher than the Mathematics Group on the reading endurance test. Table 3.3 shows adjusted mean post-test scores for measures of endurance with reading skills. There was a significant increase in mean rate of correct responding for the Reading Group only from pre-test ($M = 30.15$, $SD = 8.82$) to post-test ($M = 44.58$, $SD = 9.15$), $t(10) = -4.120$, $p < .005$. The eta squared statistic (.65) indicated a large effect size. Mean rate of correct responding decreased significantly for the Mathematics Group from pre- to post-testing.

One-way between-group analyses of covariance were conducted to evaluate the impact of the reading intervention on measures of application. After adjusting for pre-intervention rates of correct responding on ORF there was no significant difference between the two groups on post-intervention rates of correct responding.

Using the same analysis, post-intervention percentage correct scores did not significantly differ between groups either. Both groups demonstrated statistically significant increases in rate of correct responding on the same measure. The Mathematics Group's scores increased from pre-test ($M = 79.93$, $SD = 23.33$) to post-test ($M = 102.93$, $SD = 36.86$), $t(14) = -3.684$, $p < .001$. The eta squared statistic (.51) demonstrated a large effect size. The effect size for the Reading Group (.8) was larger indicating a more substantial gain in scores from pre-test ($M = 57.14$, $SD = 29.27$) to post-test ($M = 93.93$, $SD = 25.67$, $t(13) = -6.827$, $p < .001$. Mean percentage correct scores increased for the Reading Group from pre-test ($M = 90.9$, $SD = 6.82$) to post-test ($M = 97.6$, $SD = 2.25$, $t(13) = 4.38$, $p < .01$). The eta squared statistic (.62) indicated a large effect size. There was no increase in mean percentage correct scores from pre- to post-test for the Mathematics Group. Table 3.2 shows adjusted mean post-test scores for measures of application with reading skills.

3.4 Discussion

The findings of the current study demonstrated the outcomes of frequency-building and PT using each curriculum to increase fluency with component mathematics and reading skills with participants in the first and second grade (aged 6-8 years). Both groups were placed at the beginning of the instructional materials as no participant demonstrated fluency with target skills prior to intervention. Over 22 sessions, each averaging approximately 20 minutes in duration, the Mathematics Group achieved a mean of 3.6 aims ranging from zero to 15. The Reading Group were exposed to the same intensity of instruction and achieved a mean of 2.9 aims ranging from zero to nine. Results support assertions in the literature that frequency-building using PT is effective in building fluency with component academic skills

(Binder, 1996; Kubina, 2005; Hughes et al., 2007; Chiesa & Robertson, 2000). Further, both curricula were validated as effective instructional materials to build fluent component mathematics and reading skills.

Between-group analyses found differences on post-test scores of endurance and application with mathematics. This indicates that building fluent performances with mathematics skills impacted on participants' ability to endure on task for extended durations of performances, and significantly improved their ability to apply such skills to more complex mathematics problems. Significant differences between groups on measures of endurance with reading skills further supports the theory that building fluent performances is associated with an increased ability to endure for extended durations of performance. Increases in fluency with component skills demonstrated very little impact on standardised measures of ability with no significant differences on post-test scores between groups.

3.4.1 Outcomes of Frequency-Building with Mathematics

No significant differences between groups were found for subtests of the WJIII at post-testing indicating that the mathematics intervention did not impact significantly on standardised measures of mathematical ability. Scores on Applied Problems or Calculation subtests did not increase significantly for either group from pre- to post-test. However, scores on the Mathematics Fluency subtest significantly increased from pre- to post-testing for the Mathematics Group only. Further, the adjusted mean post-test score obtained from between-groups comparisons (ANCOVA) was substantially higher for the Mathematics Group (M = 111.1) than for the Reading Group (M = 105.7). Although this difference was not large enough to yield statistically significant differences using between-group analysis, results indicate that the mathematics intervention did impact the standardised measure of mathematics fluency. Further research using between-group investigations are warranted to determine if more intensive interventions impact such scores to a greater extent.

Rate of correct responding during endurance timings increased significantly for the Mathematics Group. Between-group analyses confirmed a statistically significant difference in post-test scores between groups after adjusting for pre-test scores. After exposure to frequency-building and PT using the mathematics curriculum, the Mathematics Group were able to maintain higher rates of correct responding, during prolonged timings, than the Reading Group. This result replicates the findings of Chapter 2 and supports the behavioural fluency literature proposing that the ability to engage in a skill for prolonged periods without fatiguing (Fabrizio & Moors, 2003) is improved when a fluent performance is attained with that skill.

Between-group analyses found a statistically significant difference between groups on accurate performances of application using addition and for post-test rates of correct responding on measures of application using subtraction. The Mathematics Group scored significantly higher on both measures. No significant differences were found between groups on accurate performances of application using subtraction or for rates of correct responding on the measure of application using addition. However, the between-group comparison of rates of correct responding on application using addition was close to significance ($p = .059$) with the Mathematics Group achieving a higher adjusted mean score at post-testing. Results suggest that improvements in applying component skills to more complex mathematics problems can occur when those component skills are taught fluently. Participants in the Mathematics Group demonstrated improved ability to engage in more complex mathematics tasks while participants' scores in the Reading Group did not change significantly. As discussed in Chapter 2, proponents of behavioural fluency maintain that automaticity associated with fluent component skills allows such skills to be more readily applied to more complex tasks (Binder, 1996; Chiesa & Robertson, 2000). In contrast with Chapter 2, the findings of this study support this theory.

The measure of application within the current study differed from measures employed in Chapter 2 which may explain contrasting findings. In the current study, application was assessed using the Morningside Whole Number Computation: Addition and Subtraction (Johnson & Melroe, 2006). This is synchronised with the curriculum that was used during intervention with the Mathematics Group so that participants were tested on items requiring component skills which had been targeted during intervention. Significant findings for application using this measure suggest that measures which are more closely aligned with component skills performed fluently are more sensitive to improvements on this outcome. Future research examining application as a critical outcome should investigate best practices for defining and assessing this outcome more precisely so that investigations are consistent across research studies.

3.4.2 Outcomes of Frequency-Building with Reading

There were no significant differences between groups on the reading subtests of the WJIII or the Pseudoword Decoding subtest of the WIAT-II at post-testing. However, the Reading Group showed gains in the Pseudoword Decoding measure which were close to significance. Further investigation is necessary to examine if more intensive interventions impact such measures more significantly. While the findings are similar to those for the Mathematics Group, in that increases in reading ability as measured by standardised assessments were not demonstrated, the Mathematics Group did improve significantly from pre-to post-test on the Mathematics Fluency subtest (WJIII). Participants in the Reading Group did not show significant improvements on the Reading Fluency subtest (WJIII) despite targeting fluency with component reading skills during intervention.

The Reading Fluency subtest (WJIII) assesses participants' ability to decode connected text while also comprehending what they have read (i.e., they were required to answer "yes" or "no" to indicate if each sentence read was true or false). Fluent reading of connected text was not targeted during intervention nor was reading comprehension. Component reading skills were targeted at word level only. Katzir et al., (2006) refer to the necessity for the definition of reading fluency to incorporate more than reading rate and accuracy at the word level. The authors suggest that it should include rate and accuracy at every level of reading (e.g., letter naming, word-identification and comprehension of passages). Further, a number of additional skills are required for proficient reading comprehension, such as verbal reasoning, vocabulary and oral language comprehension (Burns et al., 2011). The current study targeted only one component skill necessary to achieve fluent reading skills as measured by the WJIII which may account for the lack of significant changes on this measure. Future research should investigate the effects of building fluency with a combination of component skills on reading ability.

Significant differences between groups were found for measures of endurance with reading skills at post-testing. The Reading Groups' mean post-test rate of correct responding was significantly higher than the Mathematics Group indicating that the reading intervention impacted participants' ability to maintain higher rates of correct responding when fluent performances were attained. Scores on this measure decreased significantly for those in the Mathematics Group. Johnson and Street (2013) refer to endurance as the ability to meet real-world requirements for the duration for which behaviour must be performed. Given the length of time that students engage in reading tasks across a school day, it is essential that they achieve fluency with word decoding and obtain the ability to endure for sufficient durations of time without fatiguing. When students can sustain fluent performances over prolonged periods, more time can be spent on comprehending the text rather than decoding (Kubina & Starlin, 2003).

Oral Reading Fluency was assessed as a measure of participants' ability to apply component reading skills. Although the Reading Group made slightly larger gains than the Mathematics Group on this measure, between-group analysis confirmed that there was no significant difference between groups at post-testing. Burns et al., (2011) suggest that oral reading fluency, while closely related to automatic recognition of words in isolation, is functionally different and should be assessed and remediated independently. Katzir et al. (2006) maintain that more research should focus on rapid and accurate connected text reading, as well as fluency with word identification skills in isolation. The current study supports this assertion in that frequency-building instruction with words in isolation did not generalise to fluent reading of connected text. The non-significant finding for this measure also implies that it was not a sensitive measure for assessing application with word identification skills. This emphasises the necessity for further research investigating best practices for the assessment of this critical outcome.

3.4.3 Limitations and Future Directions

There is a paucity of between-group evaluations of frequency-building interventions and applications of curricula that address fluency skills using large sample sizes. The current research implemented both interventions with a total of 42 participants. However, due to the addition of inclusion criteria for statistical analyses and missing data, there were smaller participant numbers for some variables. Research should however, continue to evaluate such interventions with larger sample sizes and using between-group comparisons of outcomes.

Although between-group analyses allowed for the identification of differences between groups at post-tests, within-subject analyses also found that there were increases in rates of correct responding for both groups on some measures (i.e., tests of endurance with mathematics, application using addition and measures of oral reading fluency). Both groups received intervention to increase fluency with academic skills. Treatment interference may have affected post-test measures in that increasing rate of responding with one skill may have affected rates of correct responding on another. Increasing expectations of the speed at which students should engage in one academic skill may lead to their increasing the speed at which they engage in other skills. Research is necessary to investigate if such transfer effects occur in the context of frequency-building interventions and if so, should be controlled for or programmed for in future analyses.

SCCs were used to monitor and evaluate increases in rates of correct responding with target component skills in each of the Mathematics and Reading Groups. However, pre- and post-test measures of targeted component skills were not administered, so analyses could not be conducted to compare scores between groups at post-test. Future between-group designs to evaluate the effects of frequency-building instruction and PT should continue to use SCCs to investigate increases in target skills but should also include pre- and post-test measures of those skills.

Both the reading and mathematics interventions included 22 sessions, which ranged from 15-20 minutes in duration. Sessions were conducted three days per week ranging from 13 to 15 weeks in duration. As a result of intervention, participants achieved a number of fluency aims and increased scores on outcome measures from pre- to post-test; however, a more intensive intervention may have impacted outcome measures to a greater degree. As compared with the results of Study 1, a lower number of fluency aims was achieved during both the mathematics (M = 3.6, range: 0-15) and reading (M = 2.9, range: 0-9) intervention. This may have affected the ability of each intervention to impact standardised scores of mathematical and reading ability. Chapter 5 within the current thesis focuses on the impact of intervention intensity on outcome measures.

Further, standardised norm-referenced assessments of ability are likely an insensitive measure of outcomes of frequency-building interventions targeting only one key component skill. Lipsey and Hurley (2009) suggest that measures developed through sampling the content domain, representing the responses which participants are expected to acquire through intervention, are more sensitive to changes obtained from intervention than psychometric tests. Johnson and Street (2013) further assert the use of more sensitive measures to evaluate the impact of academic interventions, suggesting that “meta-level” assessments should be used. Meta-level assessments measure subsets or components of skills which are evaluated using standardised norm-referenced assessments. For this reason, they should be more sensitive to outcomes of interventions targeting component academic skills. Future studies should incorporate such assessments to evaluate frequency-building instruction with component academic skills.

3.4.4 Conclusion

Similar to Study 1, the purpose of the current study was to evaluate the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum with students in the first and second grade; however, with the addition of PT for recording and monitoring daily rates of correct responding. Findings are consistent with Chapter 2 in that frequency-building using this curriculum was effective in increasing fluency with component mathematics skills for most participants. Increases on measures of critical learning outcomes further demonstrated the benefits of implementing the current intervention within educational settings.

Consistent with the findings in Chapter 2, results of the current study indicate that additional variables may have moderated the outcomes of intervention. Similar to Chapter 2, variability in the achievement of fluency aims was demonstrated. Additionally, a substantially lower number of aims were achieved as compared with the results of Chapter 2. Younger participants, in the first grade in particular, were noted to have difficulties in achieving such aims despite achieving 100% accuracy with the same skill. Further research is warranted to investigate the impact of age on the ability to achieve specified fluency aims as well as associated differences in cognitive abilities.

The findings of both Chapter 2 and 3 indicate that individual differences may impact the outcomes of frequency-building instruction. Participants who achieved the lowest number of fluency aims in Chapter 2 also demonstrated the lowest scores on standardised measures of mathematical ability and pre-test measures of fluency. Chapter 3 implicates participant age and grade as moderating variables of instruction. Chapter 4 investigates the ability of individual differences, inclusive of mathematical ability, pre-intervention levels of fluency and participant age and grade, to moderate the effects of frequency-building instruction. The identification of such variables might facilitate the matching of instruction to individual students' needs and contribute to planning and designing effective fluency-based instruction.

Chapter 4:

Moderators of Frequency-Building Instruction: The Impact of Individual Differences on Outcomes of Intervention

4.1 Introduction

Research examining PT and fluency-based instruction to date, has demonstrated positive outcomes in relation to the efficacy of such interventions to increase rate of correct responding with targeted mathematics skills (Chiesa & Robertson, 2000; Hartnedy et al., 2005; Poncy et al., 2010). Consistent with the literature, findings reported in Chapters 2 and 3 demonstrated the efficacy of frequency-building and PT using the Morningside Mathematics Fluency: Math Facts (Johnson, 2008) curricula to achieve fluent performances with mathematics skills.

However, variability in the ability to achieve fluency aims, and the rate at which participants did so, was also demonstrated. In Chapter 2, 71% of participants achieved all targeted 26 fluency aims over varying numbers of sessions (16-30 sessions) while the remaining 29% of participants achieved between 12 and 24 fluency aims. With the addition of PT in Chapter 3, variability in responding to frequency-building was still evident. The range of mathematics fluency aims achieved was between three and fifteen with each participant receiving the same number of sessions. Further, a lower number of fluency aims was achieved across younger participants in Chapter 3 as compared to the number achieved in Chapter 2. Such findings are consistent with the literature (Bliss et al., 2010; Miller et al., 2011) indicating that individual differences may impact outcomes of interventions.

Although matching instruction to students' needs is recognised as an important component of effective instruction (Burns et al., 2010; Johnson & Street, 2013; Mong & Mong, 2012), a lack of research exists regarding how this should be addressed and how such variables should be examined prior to intervention implementation. The current study investigated individual differences, identified prior to intervention, in relation to their ability to moderate the outcomes of a frequency-building and PT intervention targeting fluency with mathematics skills. The ability to achieve such outcomes represented participants' response to the frequency-building intervention. An investigation of individual differences which impact the effectiveness of fluency-based instruction was conducted to facilitate the development of the most effective evidence-based interventions which can be matched to individual students' needs.

Findings from Chapter 2 indicated that participants who did not achieve the pre-determined number of fluency aims during intervention had lower scores on standardised measures of mathematical ability and fluency with target mathematics skills pre-intervention. Results reported in Chapter 3 found that younger participants in the first grade with a mean age of 7 years (range: 6 – 8 years) demonstrated difficulties achieving the pre-determined fluency aims. Given these earlier findings and based on research to date, the current study provided an investigation of variables, including participant age, grade, gender and pre-test assessments of mathematical ability, processing speed ability and fluency with instructional materials, as moderators of responsiveness to intervention.

Specifically, the current chapter describes two studies – Study 3 and Study 4. Study 3 provides an examination of participant age, gender, grade, pre-test scores on mathematics subtests of the WJIII and pre-test levels of fluency with instructional materials as moderators of successful outcomes of intervention. In order to achieve this, data for the twenty-four (33.8%) participants in the Mathematics Group of Study 2 were analysed along with additional data for 47 (66.2%) newly recruited participants. Newly recruited participants received frequency-building instruction with the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum, as implemented in Chapter 3, in order to achieve a larger sample size for examination of moderating variables.

To date, research has not examined the role of processing speed within the context of frequency-building interventions designed to build fluency with mathematics skills. Although some researchers have argued for its role in mathematics performance (Chong & Siegel, 2008; Geary et al., 2012), the extent to which processing speed acts as a moderator of successful outcomes of fluent performances has not been investigated. Previous research has demonstrated that age may play an important role in individuals' ability to perform specific tasks fluently (Kavé, 2006). Findings in Chapter 3 demonstrated that younger participants did not achieve a high number of fluency aims. Younger individuals demonstrate lower processing speed abilities indicating that an examination of processing speed as a moderator of frequency-building interventions is warranted. For this reason, Study 4 described in the current chapter focuses on processing speed as a potential moderator for producing successful outcomes of intervention. Processing speed was assessed with an additional newly recruited sample of 14 participants who also received frequency-building instruction with the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum, as implemented in Chapter 3.

For both Studies 3 and 4, the primary outcome that indicated successful performance was the number of fluency aims achieved by each participant indicating their ability to progress through the curriculum and frequency-building intervention. Changes in scores on four other outcome measures from pre-to post-test were also evaluated, namely standardised norm-referenced assessments of mathematical ability, fluency with instructional materials and tests of endurance and application.

4.2 Study 3

4.2.1 Method

4.2.1.1 Participants and Setting

Frequency-building and PT with mathematics skills was implemented with 71 typically developing children. The mean age of the sample was 8.75 years ranging from 6.25 to 12.8 years. Sixty-two percent (n = 44) were female and 38% (n = 27) were males. Participants were all primary level students ranging between first and sixth grade. Scores on Mathematics Fluency (WJIII) prior to intervention ranged from 65 to 145 (M = 97.8, SD = 14.9). Parental consent was obtained for all participants included in the study.

The intervention took place across three settings. Two of the settings were mainstream schools located in disadvantaged communities qualifying for participation in a School Support Programme (Delivering Equality of Opportunity in Schools; DEIS) by the Department of Education (DES, 2005). Participants in these settings consisted of 78.8% of the sample (45% and 33.8%). Fifteen of the participants (21.2%) attended an after-school homework club, developed by a community development project in a disadvantaged area, once per week. Twenty-four (33.8%) of the participants had received intervention as part of Study 2. Pre- and post-test outcomes for those participants were analysed along with the additional 47 participants recruited for this study. A final sample of 71 participants was included in Study 3.

4.2.1.2 Materials

The materials and curriculum were identical to those described in Chapter 3 for the Mathematics Group.

4.2.1.3 Procedure

Intervention sessions to increase mathematics fluency using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum were conducted with each participant. The procedure was identical to that described in Chapter 3 for the Mathematics Group and 33.8% of the sample had participated in Study 2. Participants were exposed to a mean of 19 frequency-building sessions, ranging from 9 to 26. The mean number of minutes each participant was exposed to intervention was 459 ranging from 85 to 780 minutes in total. The intervention was implemented non-concurrently across the three settings over a school year (September to June) with participants receiving a mean of 13.5 weeks of intervention ranging from 10 to 26 weeks.

There were four to six participants in each group and two to four instructors per group. Instructors included the experimenter and six Masters level students completing university postgraduate training in Applied Behaviour Analysis. Group training sessions in frequency-building, PT and use of the curriculum were provided by the experimenter for instructors prior to and throughout the course of the school year. The experimenter was also on-site, allocating time equally across the three settings, and provided individual on-site training and feedback on instructors' implementation of the intervention.

4.2.1.4 Moderators

Moderating variables included in the analyses were participant age, gender, school grade, pre-test scores on standardised assessments of mathematical ability (WJIII) and pre-test fluency scores assessed using the Morningside Math Facts: Addition and Subtraction curriculum (Johnson, 2008). Table 4.1 details moderators analysed within the current study.

Grade *(% sample)*	% Male	% Female	Mean age	Mean pre-test scores			
					Woodcock-Johnson III		
				Fluency curriculum *(range)*	Applied Problems *(range)*	Calculation *(range)*	Math Fluency *(range)*
1 *(25.4%)*	38.9	61.1	6.96	7 *(1-12)*	103.7 *(69-120)*	99.8 *(69-127)*	103.7 *(75-118)*
2 *(32.4%)*	39.1	60.9	8.03	10.3 *(4-23)*	102.2 *(71-116)*	93.2 *(53-116)*	102.2 *(73-145)*
3 *(14%)*	40	60	9.05	11.3 *(2-27)*	93.1 *(77-110)*	81 *(50-96)*	93.1 *(65-117)*
4 *(8.5%)*	33.3	66.7	9.98	12.8 *(5-26)*	85 *(60-104)*	93.5 *(79-101)*	85 *(73-94)*
5 *(7%)*	80	20	11.3	19.8 *(16-23)*	95 *(80-111)*	96.2 *(81-114)*	95 *(89-103)*
6 *(12.7%)*	11.1	88.9	12	18 *(14-21)*	88.1 *(85-108)*	99.1 *(80-126)*	88.1 *(81-96)*

Table 4.1 Mean values of Moderator variables

4.2.1.4.1 WJIII

Three mathematics subtests of the WJIII (Applied Problems, Calculation and Mathematics Fluency) were conducted with each participant pre-intervention. Applied Problems assesses quantitative reasoning, mathematics achievement and knowledge. Word problems are presented orally in conjunction with a stimulus booklet which presents problems using pictures and, at more advanced levels, words. As the problems increase in difficulty, participants are provided with a paper and pencil to help solve them. Calculation measures math achievement in relation to ability to access and apply knowledge of numbers and calculation procedures. It is a paper and pencil test involving arithmetic and computation. Participants were presented with problems on a worksheet and recorded their answers on the sheet next to each problem. The Mathematics Fluency subtest measures mathematics achievement. Specifically, the ability to access and apply automatically and with speed digit-symbol arithmetic procedures is determined. Participants were presented with a sheet of simple calculations and asked to answer as many as they could correctly in three minutes. There are two sheets in total with 80 problems on each.

4.2.1.4.2 Fluency with Instructional Materials

A review worksheet assessed fluency with mathematics skills targeted in the curriculum prior to intervention. Each participant was assessed using a worksheet which provided multiple exemplars of addition and subtraction problems pertaining to the first 12 fact families in the curriculum and addition and subtraction with one and zero. One hundred problems are presented in random order on the worksheet. Participants completed as many problems as they could during a 1-minute timing. Rate of correct responding per minute was calculated by the experimenter. All problems required one or two digit answers. A correct response was recorded if all digits in the answer to the problem were correctly written. Responses were scored as incorrect if any digit in the answer to a problem was incorrect, or if digits were omitted or placed in the incorrect order. Number of correct responses per minute was calculated to represent rate of correct responding on the test of fluency.

4.2.1.4 Outcome Measures

Moderators were analysed to evaluate their ability to moderate scores on outcomes measures or participants' "response to intervention". The primary measure of participants' response to intervention was the number of fluency aims they achieved during the intervention. Post-tests were conducted using the WJIII mathematics subtests (Applied Problems, Calculation and Mathematics Fluency) and measure of fluency with instructional materials. For each measure, changes in scores were calculated by subtracting pre-test scores from post-test scores and these values were also evaluated to measure participants' response to intervention. Measures of application and endurance were taken pre- and post-intervention as described previously in Chapter 3. Changes in scores from pre- to post-test were calculated for each participant and evaluated as a measure of participants' response to intervention.

4.2.1.5 Data Analysis

Paired samples t-tests were conducted to investigate if there were significant increases in scores on outcome measures from pre- to post-test. Pearson's product moment and Spearman's rho (for categorical variables) correlations were conducted to investigate if there were statistically significant correlations between each moderator and outcome measure. This analysis was evaluated in terms of whether moderators were associated with a higher or lower number of aims achieved and with larger or smaller increases in measures of mathematical ability (WJIII), fluency, endurance and application.

Correlation results were also used to inform the structure of multiple regression models. Hierarchical Multiple Regressions were conducted to assess the ability of the models to predict scores on outcome measures while controlling for the intensity of the intervention. Significant predictors are discussed in relation to their ability to moderate outcomes of intervention. Previous research has indicated that the intensity of an intervention can impact participants' response to intervention (Codding et al., 2011; Duhon et al., 2009; Mellard et al., 2010). Intervention within this study was implemented at differing levels of intensity. For this reason, the number of minutes of intervention received by participants was entered in the first block of the regression, to control for any impact intensity may have had on outcomes measures.

Preliminary checks were conducted with each variable to ensure there were no violations of assumptions. Outliers identified on boxplots were recoded to the nearest value in the distribution. Since variables within a Hierarchical Multiple Regression must be continuous or dichotomous, participant grade was excluded from this analysis. Kruskal-Wallis tests were conducted in order to further evaluate participant grade in relation to each outcome variable.

4.2.1.6 Social Validity

A brief questionnaire to assess social validity was administered subsequent to the intervention. The questionnaire evaluated social validity on three levels; the social significance of goals, social appropriateness of procedures and the social importance of the effects. Participants were required to select "yes" or "no" after reading a question related to participants' enjoyment of the procedure, their opinions on learning mathematics skills and how the intervention impacted their learning.

Questions were phrased differently for older and younger participants (see Appendix K).

4.2.2 Results and Discussion

The mean number of aims achieved by the sample was 5.06. Four participants achieved zero aims while the highest number achieved was 26 (n = 1). Table 4.2 shows the mean number of fluency aims achieved across participants and the mean increases in scores for the remaining outcome measures.

Outcome Measure	N	Min	Max	M *(SD)*
Number of Aims Achieved	71	0	26	5.06 *(4.49)*
Change in score Applied Problems (WJIII)	62	-10	16	2.73 (*6.55)*
Change in score Calculation (WJIII)	56	-20	23	2.36 (*10.5)*
Change in score Math Fluency (WJIII)	63	-14	31	7.59 (*9.92)*
Change in score Fluency (curriculum)	40	-2	23	7.95 (*6.09)*
Change in score Application Addition	54	-4.5	15	4.68 (*4.52)*
Change in score Application Subtraction	53	-8.5	20.5	6.42 (*6.52)*
Change in score Endurance	60	-5.8	27.2	11 (*7.18)*

Table 4.2 Descriptive statistics for number of aims achieved and scores on outcome measures from pre- to post-test

4.2.2.1 Paired Sample Statistics

Paired samples t-tests were conducted to determine if there were statistically significant differences in mean scores on outcome measures from pre- to post-testing. No significant differences in scores from pre- to post-testing were found for Applied Problems or Calculation subtests of the WJIII. There was a statistically significant increase in scores on Mathematics Fluency subtest from pre-test (M = 97.8, SD = 15.3) to post-test (M = 105, SD = 18), t (62) = -5.48, p <.001. The eta squared statistic (.33) indicated a large effect size. Significant increases in scores from pre- to post-test were also found for endurance, application and fluency with instructional materials. Table 4.3 shows mean scores pre- and post-intervention for all participants as well as the effect size associated with increases in scores.

	Pre-test score			Post-test score		Cohen's d
	N	M	SD	M	SD	
Applied problems	62	95.7	12.4	97.5	14	.03
Calculation	56	94.3	14.9	96.1	16.9	.02
Mathematics Fluency	63	97.8	15.3	105	18	.33
Fluency (curriculum)	40	12.1	6.82	19.9	11.2	.62
Application Addition	54	11.4	8.97	15.6	8.53	.41
Application Subtraction	53	11.1	8.12	17.6	10.8	.49
Endurance	60	17	9.13	27.9	14.6	.70

Table 4.3 Mean scores on outcome measures pre- and post-intervention

Although between-groups analyses were not implemented in this study, the findings support the efficacy of frequency-building and PT using Morningside Math Facts: Addition and Subtraction (Johnson, 2008) to increase fluency with mathematics skills and obtain significant outcomes for participants between the ages of six and 12 years.

4.2.2.2 Correlation Coefficients

Significant increases in scores from pre- to post-tests allowed for further analyses to investigate the relationship between moderators and the outcomes of intervention. Pearson product-moment and Spearman's rho (for categorical variables) correlation coefficients were computed to assess the relationship between each moderator and outcome measure. No significant changes in scores were found for the Applied Problems and Calculation subtests of the WJIII and therefore, they were not evaluated further as outcome measures.

Moderator	Outcome Measure	R	N
Participant age	No. aims achieved	.569**	70
Participant age	Change in fluency score (curriculum)	.344*	40
Participant age	Change in endurance score	.433**	60
Pre-test fluency score (curriculum)	No. aims achieved	.678**	42
Pre-test fluency score (curriculum)	Change in Mathematics Fluency	.381*	39
Pre-test fluency score (curriculum)	Change in fluency score (curriculum)	.455**	40
Pre-test fluency score (curriculum)	Change in endurance score	.568**	37
Pre-test fluency score (curriculum)	Change in application score	.410*	33
Participant gender	No. aims achieved	.273*	71
Participant gender	Change in Mathematics Fluency	.304*	63
Participant grade	No. aims achieved	.599**	71
Participant grade	Change in fluency score (curriculum)	.490**	40
Participant grade	Change in endurance score	.480**	60

Note. $*p < .05$. $**p < .01$. $***p < .001$.

Table 4.4 Pearson product-moment and Spearman's rho correlation coefficients indicating significant correlations between moderators and outcome measures

The relationship between participant age and each outcome measure was evaluated using Pearson product-moment correlation coefficients. There was a strong positive correlation between participant age and the number of fluency aims achieved. A moderate positive correlation was found between participant age and both changes in fluency scores with instructional materials and change in endurance scores. Table 4.4 shows correlation coefficients for significant correlations found between age and outcome measures.

Pearson product-moment correlation coefficients were also used to investigate the relationship between pre-test fluency with instructional materials and outcome measures. Correlation coefficients are shown in Table 4.4. Strong positive correlations were found between pre-test fluency scores and both the number of fluency aims achieved and changes in endurance scores. Moderate positive correlations were found between pre-test fluency with instructional materials and changes in scores on the WJIII Mathematics Fluency subtest, fluency with instructional materials and application tests using subtraction.

Spearman's rho correlation coefficients were computed to assess the relationships between participant gender and grade and each outcome measure. Table 4.4 shows correlation coefficients for significant correlations found between gender and grade and outcome measures. A small but statistically significant correlation was found between participant gender and the number of fluency aims achieved while there was a significant moderate correlation between gender and changes in scores on Mathematics Fluency (WJIII). A higher number of aims achieved and larger increases in scores on this subtest were associated with female participants. There was a strong positive correlation between participant grade and the number of fluency aims achieved while moderate positive correlations were found between participant grade and changes in scores on measures of fluency with instructional materials and on endurance tests.

Overall, findings suggest that better outcomes were associated with participants who were older, female, in higher grades and had higher rates of correct responding with instructional materials pre-intervention. Variables demonstrating significant correlations with outcome measures were further analysed in regression analyses to determine their ability to predict outcomes both as a model and in terms of each variable's unique contribution.

There were no significant correlations between pre-test scores on subtests (Applied Problems, Calculation and Mathematics Fluency) of the WJIII and outcome measures. Scores on this standardised norm-referenced assessment were not significantly associated with achieving fluency aims during intervention or changes in scores on outcome measures from pre- to post-test. Standardised norm-referenced assessments of academic achievement are valuable methods of assessment to determine if students are performing at levels similar to their same-age peers, for allocation of resource and learning support hours and to identify individual strengths and weaknesses. However, with respect to ability to inform intervention, the current study found that there was no relationship between a standardised measure of mathematical ability and response to a frequency-building intervention.

Burns et al., (2010) allude to problems with norm-referenced measures of academic achievement and their ability to inform intervention. Such measures may lack instructional relevance and there is as of yet no clear link between aptitudes and intervention effectiveness. Torgesen (2000) identifies another issue with normative approaches to assessment in that, by definition, there will always be students who fall in the lowest quartile and so will appear to be at risk regardless of their performance. Such issues with norm-referenced assessments indicate a necessity for additional assessments of instructional needs to inform best practice for mathematics instruction.

4.2.2.3 Regression Analysis

Based on significant correlations found using Pearson product-moment and Spearman's rho correlation coefficients, Hierarchical Multiple Regressions were used to investigate how well three specific variables (participant age, gender and pre-test fluency with instructional materials) predicted scores on each outcome measure. Although participant grade was significantly correlated with a number of outcome measures, it was excluded from the model as it was not an appropriate variable for this type of analysis. Standardised measures of mathematical ability (WJIII) were not significantly correlated with any outcome measures and as a result were also excluded from the model.

Participant age, gender and pre-test fluency with instructional materials significantly predicted the number of fluency aims achieved after controlling for intensity. Number of minutes of intervention was entered at step 1 and explained 15% of the variance in the number of fluency aims achieved. Participant age, gender and pre-test fluency scores were entered at step 2. Total variance explained by the model as a whole was 55%, $F (4, 37) = 11.7$, $p < .001$. Participant age, gender and pre-test fluency scores explained an additional 40% of the variance in the number of aims achieved, after controlling for intensity variables, *F* change $(3, 37) = 11.2$, $p < .001$.

Step	Variable	B	Standard error	B	R^2	R^2 change
1.	Number of Minutes	.016	.006	.392*	.154	
2.	Participant Age	.784	.325	.307*		.404
	Participant Gender	.387	1.06	.042		
	Pre-test Fluency	.292	.087	.452**		

Note. *$p < .05$. **$p < .01$.

Table 4.5 Summary of Hierarchical Multiple Regression Analysis assessing the impact of moderators on the number of fluency aims achieved

In the final model, pre-test fluency scores and participant age were statistically significant as unique predictors with pre-test fluency recording a higher beta value. Higher scores on pre-test measures of fluency and a higher participant age predicted a higher number of aims achieved. Table 4.5 shows the beta values for each variable.

The number of fluency aims achieved during intervention was the primary outcome measure used to demonstrate participants' ability to progress through the frequency-building intervention. Pre-test fluency with instructional materials best predicted this ability with those who had higher levels of pre-test fluency achieving more aims. Findings indicate that sampling rate of correct responding with instructional materials is beneficial when deciding whether or not to implement frequency-building with mathematics skills. This finding supports Burns' et al., (2010) suggestion that sampling students' levels of correct responding with instructional materials can inform instructional planning in terms of the appropriateness of fluency-based instruction for individual students.

Burns et al. (2006) assert that students can be confronted with academic difficulties when a mismatch is made between a student's skill level and instructional material. It is essential that instructional material is challenging enough and yet not too easy. The authors note that students who show the strongest growth are students for whom the task represents an appropriate instructional match. The current study supports this assertion. Students who had lower pre-test fluency scores required more untimed practice and corrective feedback between frequency-building timings and did not achieve as many fluency aims. Acquisition interventions targeting accurate responding with mathematics skills would perhaps be more beneficial for such students before frequency-building interventions are implemented.

Alternatively, frequency-building in conjunction with other instructional approaches (e.g., DPR; Poncy et al., 2013) should be evaluated for appropriateness with such students.

Participant age was also a unique predictor of participants' ability to achieve fluency aims. Pre-test levels of fluency were also lower for younger participants indicating that they may equally have benefited from acquisition interventions prior to exposure to frequency-building. However, fluency aims as outlined by the Morningside Math Facts: Addition and subtraction (Johnson, 2008) curriculum were challenging. Kavé (2006) found that age plays an important role in individuals' ability to perform tasks fluently. Recommended fluency aims should likely be differentiated based on student age as opposed to recommending one general fluency range for academic skills. Research is warranted to investigate optimal fluency aims as differentiated by age (i.e., can achievement of lower fluency aims lead to the same outcomes associated with fluency with younger children).

Gender was not found to be a unique predictor in the final model and demonstrated only a weak correlation with the number of fluency aims achieved. Further analysis demonstrated that the mean number of aims achieved was slightly higher for girls but there was no significant difference between boys ($M = 3.89$, $SD = 4.06$) and girls ($M = 5.77$, $SD = 4.63$) for number of aims achieved, $t(69) = 1.74$, $p = .086$. Carr et al. (2008) found that girls demonstrated lower fluency scores with mathematics skills than boys; however, the results of the current study suggest that gender does not affect ability to achieve fluency with mathematics skills given appropriate instruction.

4.2.2.4 Kruskal-Wallis

Participant grade was not an appropriate variable for inclusion in regression analyses. Therefore, Kruskal-Wallis tests were used to evaluate differences in outcome measures across the six grades. Statistically significant differences in the number of fluency aims achieved, χ^2 (5, n = 71) = 27.4, p < .001, change in fluency scores with instructional materials, χ^2 (5, n = 40) = 12.8, p < .05 and change in endurance scores, χ^2 (5, n = 60) = 13.95, p < .05 from pre- to post-test were found across six grades (first to sixth grade). Participants in higher grades demonstrated the highest rank scores for each outcome measure and lower grades demonstrated the lowest. Sak and Maker (2006) found significant differences in fluency with mathematics skills across grades. The current findings indicate that there is also a difference in students' ability to achieve fluent performances across grades. Student grade should be accounted for when developing frequency-building interventions in a similar manner to student age.

Table 4.7 shows the mean increases in scores on outcome measures from pre- to post-tests across the six grades. Larger increases in scores on outcome measures are seen for the higher grades. Mean age, mean number of aims achieved and mean pre-test fluency scores across grades are also shown. Applied Problems and Calculation (WJIII) subtests are not included since there was no statistical difference between pre-and post-test scores for this sample.

Grade	N	Age	Pre-test Fluency	No. of aims achieved	Woodcock-Johnson Math Fluency	Endurance	Application Addition	Application Subtraction	Fluency (curriculum)
		Mean	Mean *(N)*	Mean	Mean change in score *(SD)*	Mean change in score *(SD)*	Mean change in score *(SD)*	Mean change in score *(SD)*	Mean change in score *(SD)*
1	18	6.96	7 *(7)*	1.9	8.44 *(8.77)*	6.28 *(5.98)*	5.8 *(5.19)*	5.4 (5.85)	2.71 *(3.73)*
2	23	8.03	10.3 *(9)*	4.4	2.53 *(11.9)*	11.1 *(6.82)*	2.95 *(3.31)*	5.4 (5.74)	5.89 *(5.46)*
3	10	9.06	11.3 *(10)*	5.3	9.6 *(7.35)*	12.9 *(6.87)*	6.15 *(4.4)*	8.35 (6.46)	10.8 *(6.03)*
4	6	9.98	12.8 *(5)*	5.2	12.3 *(8.64)*	13.8 *(6.15)*	4.67 *(3.72)*	3.5 (7.26)	7.4 *(5.22)*
5	5	11.3	19.8 *(5)*	8.6	10.5 *(7.72)*	15.4 *(7.07)*	5.75 *(3.18)*	17.5 (4.24)	10.8 *(8.81)*
6	9	12	18 *(6)*	10.8	11 *(9.2)*	18.4 *(5.82)*	4.25 *(12.4)*	17	11.6 *(3.21)*

Table 4.7 Overview of significant moderators and outcome measures across grades

4.2.2.5 Social Validity

The social validity questionnaire was completed by 63% (n = 45) of the sample. The majority of participants answered that they thought the goals (i.e., mathematics skills) that they were working on were important, that they enjoyed the procedure and that it helped with their work in class. The social validity of procedures and goals of instruction from students' perspective is important so that they are motivated to take part in it. The finding that a high percentage of participants enjoyed taking part is a positive outcome for applying interventions such as the current one in educational settings. Table 4.8 shows participants' responses to social validity questions.

	Social Validity Questions	Yes	No
1	It's important to learn your maths well	96% (n = 43)	4% (n = 2)
2	I liked practicing my maths	89% (n = 40)	11% (n = 5)
3	I learned my maths well	93% (n = 42)	7% (n = 3)
4	I liked trying to get my goal	100% (n = 45)	0% (n = 0)
5	I can add and take away faster now	89% (n = 40)	11% (n = 5)
6	I liked working really fast and trying to beat the timer	93% (n = 42)	7% (n = 3)
7	I can do my maths faster in class now	89% (n = 40)	11% (n = 5)
8	Getting my goals made me feel good	100% (n = 45)	0% (n = 0)
9	(a) It's important to know your adding and taking away off by heart	98% (n = 44)	2% (n = 1)
	(b) This helps me do my maths better	98% (n = 44)	2% (n = 1)

Table 4.8 Percentages endorsing either 'Yes' or 'No' for social validity questions

4.3 Study 4

Processing speed can be defined as the speed of completion of a task with reasonable accuracy and is usually measured with tasks such as quickly associating numbers with symbols, searching for and responding to specific targets, and rapid naming of visual stimuli (Jacobson et al., 2011*)*. Research has demonstrated a relationship between processing speed and mathematical ability (Geary et al., 2012) and math fact fluency (Chong & Siegel, 2008). However, to date, research has not examined the role of processing speed within the context of frequency-building interventions designed to build fluency with mathematics skills. Study 3 demonstrated that participant age moderates participants' response to frequency-building instruction. Since younger individuals generally demonstrate lower processing ability, it follows that processing speed should also be investigated as a moderator of frequency-building instruction. Study 4 provides an evaluation of the relationship between performance on processing speed tasks and performance within frequency-building interventions designed to increase fluency with mathematics skills.

4.3.1 Method

4.3.1.2 Participants and Setting

Participants were an additional sample of 14 typically developing students with a mean age of 9.88 (ranging from 9.25 to 10.7) attending a mainstream primary school in fourth grade. Fifty percent (n = 7) of the sample were female and 50% (n = 7) were male. Scores on Mathematics Fluency (WJIII) prior to intervention ranged from 80 to 114 (M = 96.4, SD = 12.8). Frequency-building sessions using PT took place in a resource classroom with four to five students and two to three experimenters.

4.3.1.3 Materials

The materials and curriculum were identical to those used in Study 3.

4.3.1.4 Procedure

Participants were exposed to frequency-building and PT using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum to increase mathematics fluency for five weeks, three to four times per week for 30-minutes. The procedure was the same as was described in Study 3.

4.3.1.5 Moderators

Moderating variables included in the analyses were pre-test scores on the Processing Speed Index (PSI) of the Wechsler Intelligence Scale for children, Fourth Edition (Wechsler, 2003), pre-test scores on the Mathematics Fluency subtest of the WJIII, and pre-test fluency with instructional materials assessed using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum. Table 4.9 shows the mean scores for the sample on each variable.

	N	Min	Max	M *(SD)*
Number of Aims Achieved	14	3	30	14.2 *(8.99)*
Pre-test PSI	14	83	141	106 *(14.6)*
Pre-test Math Fluency (WJIII)	14	80	114	96.4 *(12.8)*
Pre-test Fluency (curriculum)	14	9	43	22.1 *(10)*

Table 4.9 Mean and range values for moderators in Study 4 and number of fluency aims achieved

4.3.1.5.1 Processing Speed Index

Two subtests are conducted within this index to calculate an overall measure of processing speed. Coding involves copying symbols that are paired with numbers within a specific time limit. Participants' scores are determined by the number of symbols correctly drawn within 2 minutes. Measured within this subtest are speed and accuracy, incidental learning, visual-motor dexterity and non-verbal short-term memory. Symbol search involves scanning a search group of abstract symbols and indicating if a target symbol/s matches any of the symbols in the search group with a specific time limit. Scores are determined by the number of correct matches made within 2 minutes. Measured within this subtest are mental processing accuracy, perception and recognition and attention and concentration. Scaled scores for each subtest are calculated to obtain an overall processing speed score.

4.3.1.5.2 Mathematics Fluency (WJIII)

Mathematics fluency was measured in an identical format to that described in Study 3.

4.3.1.5.3 Fluency with Instructional Materials

Fluency with instructional materials was measured in an identical format to that described in Study 3.

4.3.1.5 Outcome Measures

Moderators were evaluated in terms of their relationship with participants' "response to intervention". Similar to Study 3, the number of fluency aims achieved during the five week intervention represented participants' response to intervention. Table 4.9 shows the mean number and range of fluency aims achieved by the sample.

4.3.1.6 Data Analysis

The sample size within this study did not permit regression analyses to be conducted. Pearson's product moment correlations were conducted to investigate if there were statistically significant associations between pre-intervention PSI scores and the number of fluency aims achieved during intervention. The relationship between the number of aims achieved and pre-test measures of fluency (with instructional materials and as measured by the WJIII) was also evaluated using Pearson's product moment correlation coefficients.

4.3.2 Results and Discussion

The mean number of fluency aims achieved by the sample was 14.2. The lowest number of aims achieved by any participant was 3 (n = 3), while the highest number achieved was 30 (n = 2). Table 4.9 shows the mean number of fluency aims achieved and mean pre-test scores on each measure.

4.3.2.1 Correlation Coefficients

Pearson product-moment correlation coefficients were computed to assess the relationship between pre-test PSI scores, pre-test scores on Mathematics Fluency (WJIII), pre-test fluency with instructional materials and the number of fluency aims achieved. Table 4.10 shows correlation coefficients for significant correlations found between moderators and outcome measures.

Moderator	Outcome Measure	R	N
Pre-test PSI	No. aims achieved	.672**	14
Pre-test Mathematics Fluency (WJIII)	No. aims achieved	.763**	14
Pre-test Fluency (curriculum)	No. aims achieved	.646*	14

*Note. *p < .05. **p < .01. ***p < .001.*

Table 4.10 Pearson product-moment coefficients between moderators and number of aims achieved

There was a strong positive correlation between pre-test PSI and number of aims achieved. A strong positive correlation was also found between pre-test Mathematics Fluency (WJIII) and number of aims achieved. There was a large positive correlation between pre-test fluency with instructional materials and the number of fluency aims achieved.

Consistent with Study 3, pre-test fluency with instructional materials demonstrated a significant and large relationship with the number of fluency aims achieved. However, unlike Study 3, Mathematics Fluency (WJIII) also demonstrated a relationship with achieving fluency aims indicating that further investigation is warranted to investigate its ability to moderate frequency-building instruction. Processing speed also demonstrated a significant relationship with the number of aims achieved during the five weeks of intervention. Results indicate the potential importance of considering processing speed when developing frequency-building interventions. For example, instructors should be cautious with regards to selecting fluency-based instructional methods and when setting high fluency aims for students with lower processing speed abilities. Similar to the implications of age as a moderator of frequency-building, fluency aims should possibly be differentiated based on processing speed ability as opposed to recommending one general fluency aim for skills targeted for frequency-building. Since regression analyses were not possible within the current study, further research is warranted to investigate the ability of age, processing speed and pre-test fluency scores to moderate frequency-building instruction as well as determine which variables moderate outcomes to the greatest degree.

4.4 General Discussion

Some inconsistencies in ability to achieve fluent performances subsequent to fluency-based interventions have been noted in the literature (Bliss et al., 2010; Miller et al., 2011). Further, variability in the number of fluency aims achieved was demonstrated in Chapters 2 and 3. This variability in performance indicates the necessity to investigate individual differences that potentially moderate the effectiveness of fluency-based interventions in order to inform more effective intervention and implementation. The studies reported in the current chapter investigated moderators of participants' response to a frequency-building intervention using PT and the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) to increase fluency with mathematics skills. A number of significant findings should be emphasised and considered when planning and delivering effective interventions with mathematics skills.

It is essential that frequency-building interventions and curricula to increase mathematics skills are evaluated (Poncy et al., 2013) so that empirically validated methods of instruction can be implemented within educational settings. Equally as important is the examination of factors which moderate the effects of such interventions and the identification of students for whom frequency-building is appropriate. Consequently, the finding that pre-test fluency scores moderate outcomes of frequency-building instruction is significant with implications for applying such instruction in educational settings. Burns et al., (2006) assert that academic tasks presented to students should represent an instructional match to the ability of each student but that few studies have examined students' level of fluency pre-intervention to inform instructional programming. The findings of Study 3, reported in the current chapter support the assertion that instruction, specifically frequency-building instruction, should be matched to student skill level using fluency with instructional materials as a pre-intervention assessment. Outcomes of frequency-building and PT were greater for those with a higher pre-intervention level of fluency.

Results also support evidence for a Response to Intervention (RTI) framework of assessment and intervention with mathematics skills. Within the RTI framework, an emphasis is placed on differential instruction for differing educational needs of each student (Gettinger & Stoiber, 2012; Lembke, Hampton & Beyers, 2012; NCRI, 2010; 2). Lembke et al. (2012) describe the critical elements of RTI in mathematics. Two key elements of RTI are screening and progress monitoring wherein students are assessed to evaluate their performance and inform instruction. Along with norm-referenced assessments, meta-level assessments are administered on a weekly, monthly or quarterly basis. Meta-level assessments measure performance on a subset of skills that best predict mastery of related skills. They typically measure mastery of component skills which are pre-requisites to mastery of composite repertoires which norm-referenced assessments measure (Johnson & Street, 2013).

The current findings indicate that meta-level assessments should be used in conjunction with norm-referenced assessments to best inform instruction. Scores on subtests of the WJ III did not demonstrate a significant relationship with outcomes measures. The results described herein indicate that it may be beneficial to incorporate meta-level assessments of fluency and accuracy with specific skills in educational settings to inform instructional methods appropriate for each individual student. Specifically, when implementing frequency-building with the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum, pre-test levels of fluency may be investigated prior to implementing frequency-building instruction. Further research is necessary to investigate the exact level of pre-test fluency necessary in order to achieve optimal outcomes with participants.

The findings in Study 3 demonstrated that participant age moderated achievement of fluency aims during intervention and showed significant differences in the number of fluency aims achieved across school grades. Such findings indicate the importance of considering these variables when planning and implementing effective frequency-building instruction. There are a number of reasons why participant age may have moderated the effects of intervention. Younger participants in lower grades demonstrated lower fluency with instructional materials pre-intervention. Pre-test fluency was also found to be a moderator of the number of aims achieved. The mean pre-test fluency level of the first grade group was seven correct responses per minute while those in the sixth grade had a mean pre-test fluency level of 18 correct responses per minute. Following this, the first grade group only achieved a mean of 1.9 aims during intervention while the sixth grade group achieved a mean of 10.8 fluency aims. Mean increases in fluency scores with instructional materials from pre-to post-test for the first grade group was only 2.71 correct responses per minute while the mean increase in sixth grade was 11.6 correct responses per minute.

Another possible reason for the moderating effects of participant age on outcomes of intervention is that processing speed may play an important role in the achievement of fluency aims. A correlation between pre-test processing speed and the number of aims achieved was found for 14 participants in Study 4. While further investigation is necessary to examine processing speed as a moderator of intervention outcomes, preliminary results reported in the current chapter suggest that processing speed does play a role in frequency-building interventions and should be considered for effective intervention design and planning. Students' processing speed abilities should be considered relative to the suitability of individuals for instruction aimed at building fluency with academic skills, the development of fluency aims and the allocation of instruction time allowed for students to achieve such aims.

Findings in Study 3 and 4 indicate that when implementing frequency-building in educational settings, participant age, grade and processing speed ability should all be considered when deciding the appropriateness of such instruction with each individual student. Specifically, the current research indicates that when building fluency with the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum, students from second grade and upwards demonstrate the best ability to achieve the pre-determined fluency aims.

4.4.1 Limitations and Future Directions

Larger sample sizes would be beneficial to increase the external validity of such findings, in particular, since measures of pre-intervention fluency were not attainable for all 71 participants in Study 3. Despite a small sample size in Study 4 (n = 14), a large correlation was found between PSI and the achievement of fluency aims during intervention. However, regression analyses were not permitted to investigate the ability of processing speed to moderate outcomes within a model, inclusive of participant age and pre-test fluency with instructional materials, or evaluate its ability to uniquely moderate such outcomes. Further research is warranted to investigate the role of processing speed within frequency-building interventions and examine its moderating effects on outcomes of intervention.

A number of additional possible moderating variables were not assessed as they were outside the scope of the current research. Torgesen (2000) for example, investigated cognitive, language, behavioural and demographic characteristics in relation to reading ability. They found that children who showed the poorest growth in reading ability came from homes in which parents had the lowest levels of education and income and were related by their teachers as showing the broadest range and highest frequency of behaviour problems in the classroom. Cognitive abilities (e.g., working memory) and behaviour problems have been linked with fluent performances by behavioural fluency theorists (Binder et al., 2002; Bliss et al. 2010; Miller et al., 2011). Such links should be investigated and evaluated experimentally and research on moderators of frequency-building expanded.

Based on the findings that individual differences moderate participants' ability to achieve fluency aims, further research is necessary to examine the best methods for setting such aims for students. Currently, educators are recommended to look to previous research or sample a skill with a group of fluent learners in order to set a fluency aim (Kubina & Yurich, 2012). However, since individual differences have been shown to moderate achievement of fluency aims, setting such targets based on other students' performances may not be the best approach. It would be beneficial in educational settings to understand such individual differences further in terms of setting appropriate fluency aims for individual students which can result in critical outcomes associated with fluent performance. Further investigation, along with the findings in the current study, may allow for pre-intervention information and assessments to inform appropriate aims for each individual student.

In particular, further investigation is warranted to clarify the role of processing speed within frequency-building interventions and its ability to inform the allocation of appropriate fluency aims for individual students. Individual differences in processing speed have been demonstrated in the research (Jarrold, Mackett & Hall, 2014; Vinkhuyzen et al., 2010) and deficits in processing speed ability have been found with individuals with Traumatic Brain Injury (Battistone, Woltz & Clark, 2008), children with ADHD (Dickerson Mayes & Calhoun, 2007; Jacobson et al., 2011) and children with autism, bipolar disorder and learning disorders (Calhoun & Dickerson Mayes, 2005). With such differentiated abilities among individuals, processing speed should be considered before implementing interventions aimed at increasing speed of responding.

Further, processing speed deficits have been associated with the ability to learn in a classroom and concentrate (Jarrold et al., 2014), increased rates of inattention and overactive/ impulsive behaviour (Mulder, Ptichford & Marlow, 2011), communication ability in children with autism (Oliveras-Rentas et al., 2012), deficits in reading (Leonard et al., 2011), and mathematics abilities (Chong & Siegel, 2008). Since processing speed has been identified as an important general ability, research on increasing speed of responding with academic skills should assess if generalised effects are demonstrated with standardised measures of processing speed.

4.4.4 Conclusion

The current chapter investigated individual differences among participants as moderators of frequency-building instruction. Results indicate the importance of considering such variables when developing and implementing such instruction. The findings in Chapter 2 and 3, and previous research, have indicated the importance of also considering intensity of intervention as a moderator of participants' response to intervention (Codding et al., 2011; Duhon et al., 2009; Mellard et al., 2010). Within the RTI framework, increases in intervention intensity are prescribed based on students' unresponsiveness to their current instruction (Codding et al., 2009; Johnson & Street, 2013). For students who are identified as having difficulties within a curricular area, increasing intensity of instruction in that area is considered a vital component of intervention in order to remediate skill deficits. However, a limited amount of research has investigated intensity of interventions, in terms of its definition and its impact on intervention outcomes. Chapter 5 investigates the role of intervention intensity within the context of frequency-building instruction.

Chapter 5:

Quantification and Evaluation of Intensity of Frequency-Building Instruction

5.1 Introduction

Chapter 4 investigated the ability of individual differences to moderate the effects of a frequency-building intervention. The results emphasise the importance of considering factors such as participant age and grade, pre-intervention levels of fluency and processing speed ability prior to implementing frequency-building instruction. Chapter 5 further investigates possible moderators of such instruction with a focus on the ability of intensity of intervention to moderate outcomes of intervention.

Participants in the Experimental Group in Chapter 2 demonstrated increases in composite scores of mathematical ability (WIAT-II) and on tests of application. However, those increases were not large enough to yield significant differences in scores when compared to those of the Control Group. Further, scores on the Mathematics Fluency subtest of the WJIII increased significantly for the Mathematics Group only in Chapter 3; however, significant differences in scores were not found on post-test measures between groups. Such findings implicate intensity of instruction as a moderator of frequency-building instruction.

A limited amount of research has been conducted to investigate intensity in terms of its ability to moderate interventions (Codding et al., 2011; Duhon et al., 2009; Mellard et al., 2010). Considering the implications for both research *and* applied practice, intensity is a concept which merits much empirical investigation. However, in addition to a lack of research investigating intensity as a moderator, issues have been reported in the literature in terms of its quantification. Barnett, Daly, Jones and Lentz (2004) assert that many variables have been used to measure intensity and that it is a concept in need of further development and scrutiny.

Across the literature, intensity has been quantified as related to number of minutes per session, instructional group size (Ardoin et al., 2006; Mellard et al., 2010), number of sessions (Ardoin et al., 2006), the number of opportunities to respond (Fuchs & Fuchs, 2001; Mellard et al., 2010), frequency and duration of instruction, immediacy of corrective feedback, mastery requirements of the content, number of transitions among contents, the specificity of curricular goals and instructor speciality and skills (Mellard et al., 2010).

Duhon et al. (2009) argue that a number of research studies have been conducted to evaluate the impact of varying intervention intensities on fluency-based instruction. However, they suggest that the relationship between intensity and the outcomes of intervention have been obscured since the quantification of intensity has not been consistent across the research. Thus, evaluating the impact of the intensity at which interventions are implemented is difficult. Duhon et al. (2009) further suggest that increasing the intensity of an intervention can be accomplished by increasing a single dimension (i.e., frequency of sessions conducted) and in doing so a metric can be calculated to allow for quantifiable comparisons of intervention intensities.

Few studies have investigated the ability of differing levels of intensity to moderate outcomes of frequency-building instruction using this approach. As discussed in Chapter 1, Duhon et al. (2009) evaluated the impact of increased intensities of a frequency-building intervention with mathematic skills. Intensity was quantified as the frequency of sessions implemented per day. Results demonstrated that increased frequencies of sessions impacted outcome measures. Hale (2009) further demonstrated the ability of a higher frequency of sessions to increase fluency with mathematics skills to a greater extent than a lower frequency of sessions. Such research highlights the importance of both quantifying and evaluating intensity in terms of its ability to moderate outcomes of intervention. However, to date, it is an area that has had limited empirical consideration (Duhon et al., 2009).

The current study aims to investigate intervention intensity in order to add to emerging research seeking to quantify intensity and evaluate its ability to moderate outcomes of frequency-building instruction with mathematics skills. Codding et al. (2011) implicate intervention "dose" as a critical variable to consider in terms of intervention intensity. Variables associated with intervention dose incorporate such variables as minutes of instruction, frequency and duration (Mellard et al., 2010). The current research investigated five dimensions associated with intervention dose.

Previous research has indicated that the frequency of sessions (Duhon et al., 2009; Hale, 2009), the number of minutes in intervention, the number of sessions (Ardoin et al, 2006), the duration of intervention (Hale, 2009) and rates of active responding (Fuchs & Fuchs, 2001) influence outcomes of intervention. For this reason, frequency of sessions, number of minutes of intervention, number of sessions, number of weeks in intervention and number of timings were analysed to determine if varying levels of each dimension was significantly associated with scores on outcome measures. This analysis was conducted in an effort to identify dimensions which are best manipulated when increasing the intensity of frequency-building interventions. Hierarchical Multiple Regressions were subsequently applied to investigate the ability of intervention dose to moderate scores on outcome measures.

In order to achieve this, data for the 71 participants in Study 3 were analysed. As described in Study 3, frequency-building instruction was implemented with mathematic skills using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum. The primary outcome that indicated successful performance was the number of fluency aims achieved by each participant indicating their ability to progress through the curriculum and frequency-building intervention. Changes in scores on four other outcome measures from pre- to post-test were also evaluated, namely standardised norm-referenced assessments of mathematical ability, fluency with instructional materials and tests of endurance and application.

5.2 Method

5.2.1 Participants and Setting

The participants and settings were the same as those reported in Study 3 of Chapter 4.

5.2.2 Materials

The materials and curriculum were identical to those outlined in Chapter 3 for the Mathematics Group.

5.2.3 Procedure

Participants were exposed to frequency-building and PT using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum as outlined in Chapter 4. Analyses investigating intervention intensity were conducted using the same data as was used in Study 3 of Chapter 4. Varying intensities of intervention were implemented with the sample. A mean of 19 frequency-building sessions, ranging from 9 to 26 was conducted. The intervention was implemented non-concurrently across the three settings over a full school year (September to June) with participants receiving a mean of 13.5 weeks of intervention ranging from 10 to 26 weeks. The mean number of minutes each participant was exposed to intervention was 459 ranging from 85 to 780 minutes in total. The procedure was identical to that described in Chapter 3 for the Mathematics Group.

5.2.4 Moderators

Moderating variables related to intensity, specifically intervention dose included the total number of timings implemented across sessions, the total number of minutes each participant received instruction, the number of weeks across which instruction took place and the number and frequency of sessions (average number of sessions implemented per week). Table 5.1 shows the mean for each variable for the sample.

	N	Min	Max	Mean (SD)
Number of sessions	71	6	26	19 (4.36)
Number of explicit timings	71	13	132	81.1 (23.3)
Number of minutes	71	85	780	459 (135)
Number of weeks	71	10	26	13.5 (4.19)
Frequency of sessions	71	.25	2.20	1.54 (.51)

Table 5.1 Mean and range values for moderating variables

5.2.5 Outcome Measures

Moderators associated with intensity were evaluated in relation to their ability to impact scores on outcome measures. The outcome measures investigated in this study were the same as those described in Study 3 of Chapter 4. Similarly, the number of fluency aims achieved by participants throughout the intervention was the primary outcome measure. Changes in scores from pre-to post-test on measures of fluency with instructional materials, application and endurance and on the Mathematics Fluency subtest of the WJIII were also evaluated. As outlined in Study 3 of Chapter 4, there were no significant increases in scores on the Applied Problems or Calculation subtests of the WJIII; therefore, they were excluded as outcome measures. As with Study 3, changes in scores were calculated for each measure by subtracting pre-test scores from post-test scores to obtain the change in score for each participant from pre-to post-test.

5.2.6 Data Analysis

As described in Study 3 of Chapter 4, paired samples t-tests were conducted to investigate if there were significant increases in scores on outcome measures from pre- to post-testing. Pearson's product moment correlations were conducted to investigate if there were significant correlations between each outcome measure and moderator. Correlation analyses were evaluated to determine whether moderating variables were significantly associated with a higher or lower number of aims achieved and larger or smaller increases from pre- to post-test on measures of fluency, endurance and application and on the Mathematics Fluency subtest of the WJIII.

Correlation results were also used to inform the structure of the multiple regression model evaluated in this study. Hierarchical Multiple Regressions were conducted to assess the ability of the model to predict scores on outcome measures while controlling for individual differences. Significant predictors are discussed in relation to their ability to moderate outcomes of intervention. The results of Study 3 found that participant age, gender and pre-test fluency as a model significantly moderated scores on outcome measures. For this reason, they were entered in the first block of the regression to control for their impact on outcome measures. Preliminary checks were conducted with each variable to assess for violations of assumptions. Outliers identified on boxplots were recoded to the nearest value in the distribution.

5.3 Results

The results of Study 3 outlined in Chapter 4 showed that the mean number of fluency aims achieved by the sample was 5.06. Four participants achieved zero aims while the highest number achieved was 26 (n = 1). Paired samples t-tests found significant increases in scores on measures of fluency with instructional materials, endurance and application and on the WJIII Mathematics Fluency subtest. The mean number of aims achieved and mean increases in scores on outcome measures from pre- to post-test are shown in Table 4.2. No significant differences in scores from pre- to post-testing were found for the Applied Problems or Calculation subtests of the WJ III.

5.3.1 Correlation Coefficients

Significant increases in scores from pre- to post-tests on measures of fluency with instructional materials, endurance, application and on the Mathematics Fluency subtest of the WJIII allowed for further analyses to investigate the relationship between each outcome and moderating variable. No significant changes in scores were found for the Applied Problems and Calculation subtests of the WJIII; therefore, they were not evaluated further as outcome measures.

Pearson product-moment correlation coefficients were computed to assess the relationship between each moderator and outcome measure. The number of minutes that participants were exposed to frequency-building instruction correlated significantly with a higher number of outcome measures than the remaining moderators. There were positive correlations between the number of minutes of intervention received and the number of fluency aims achieved during intervention, changes in scores on the Mathematics Fluency subtest of the WJIII and with changes in scores on measures of fluency with instructional materials and endurance. Table

5.2 shows the correlation coefficients for significant correlations found between number of minutes and outcome measures. Each outcome measure demonstrated a moderate positive correlation with number of minutes of intervention received. A higher number of minutes of intervention received was associated with a higher number of fluency aims achieved and larger increases in scores on Mathematics Fluency (WJIII), fluency with instructional materials and tests of endurance.

Intensity variable	Outcome Measure	R	N
Number of minutes	Number of aims achieved	.391**	70
Number of minutes	Mathematics Fluency (WJIII)	.307*	63
Number of minutes	Fluency with instructional materials	.338*	40
Number of minutes	Endurance	.342**	60
Number of sessions	Mathematics Fluency (WJIII)	.250*	63
Frequency of sessions	Mathematics Fluency (WJIII)	.274*	63
Number of weeks	Mathematics Fluency (WJIII)	-.269*	63

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 5.2 Pearson product-moment correlation coefficients indicating significant correlations between moderators and outcome measures

The number of frequency-building sessions implemented significantly correlated with changes in scores on the Mathematics Fluency subtest of the WJIII demonstrating a small, positive correlation. A higher numbers of sessions implemented was associated with larger increases in scores on Mathematics Fluency (WJIII) from pre- to post-test. The frequency of sessions was also significantly correlated with changes in scores on the Mathematics Fluency (WJIII) subtest, demonstrating a small positive correlation. A higher number of sessions per week or frequency of sessions was associated with larger increases in scores on Mathematics

Fluency (WJIII). Table 5.2 shows correlation coefficients for significant correlation between the number and frequency of sessions and Mathematics Fluency (WJIII).

The number of weeks from the first session to the last was also significantly correlated with Mathematics Fluency (WJIII). A weak negative correlation indicated that a higher number of weeks across which instruction took place was associated with smaller increases in scores on this measure. Table 5.2 shows the correlation coefficient for the correlation between number of weeks and Mathematics Fluency (WJIII). The number of timings implemented with participants was not significantly correlated with any of the outcome measures.

Overall, significant correlations demonstrated that a larger intervention dose was significantly associated with larger changes in scores on outcome measures. The number of minutes for which participants' were exposed to frequency-building instruction was the only moderator which was significantly correlated with the number of fluency aims achieved during intervention, which was the primary outcome measure of this study. The results of Pearson product-moment correlations were used to analyse intensity further and determine its ability to moderate outcome measures.

5.3.2 Regression Analysis

Hierarchical Multiple Regressions were conducted to investigate if intensity significantly predicted scores on outcome measures and as such moderated the effects of frequency-building instruction. Preliminary checks were conducted to assess for violations of assumptions. Significant correlations were demonstrated between each moderating variable and thus only one variable could be included in the regression to evaluate intervention dose. Table 5.3 shows the significant correlations between intensity variables.

Variable	1	2	3	4	5
1. Number of sessions	-	.685**	.813**	.865**	-.492**
2. Number of minutes		-	.657**	.575**	-.336**
3. Number of timings			-	.763**	-.532**
4. Frequency of sessions				-	-.833**
5. Number of weeks					-

Note. $^{**}p < .01$.

Table 5.3 Pearson product-moment correlations showing significant correlations between moderators

The findings reported in Study 3 of Chapter 4 demonstrated the ability of individual differences namely, participant age, gender and pre-test fluency with instructional materials as a model to predict scores on outcome measures. For this reason, they were entered in the first block of the Hierarchical Multiple Regression. The number of minutes of frequency-building instruction received was entered in the second block to investigate intervention dose as a moderator of frequency-building instruction while controlling for individual differences. The number of minutes was included in the Hierarchical Multiple Regression since it was the only moderator which correlated significantly with the primary outcome measure - the number of fluency aims achieved. Pearson product-moment correlation coefficients also demonstrated significant correlations between number of minutes and increases in scores on the Mathematics Fluency subtest of the WJIII and measures of fluency with instructional materials and endurance.

After controlling for individual differences, the number of minutes of frequency-building instruction received did not significantly moderate scores on any of any outcome measures investigated. Table 5.4 shows the results of the Hierarchical Multiple Regression conducted to assess the ability of intervention dose to moderate the number of fluency aims achieved during intervention. Participant age, gender and pre-test fluency scores were entered at step 1 and explained 53% of the variance in the number of aims achieved. Number of minutes was entered at step 2. Total variance explained by the model as a whole was 56 %, F (4, 37) = 11.7, p < .001. Number of minutes explained only an additional 3% of the variance, *F* change (1, 37) = 2.18, p = .148.

Step	Variable	B	Standard error	B	R^2
1.	Participant age	.794	.330	.311*	.532
	Participant gender	.677	1.055	.074	
	Pre-test fluency	.324	.086	.502**	
2.	Number of minutes	.007	.005	.174	.026

*Note. *p < .05. **p < .01.*

Table 5.4 Summary of the Hierarchical Multiple Regression assessing the ability of intervention dose to moderate the number of fluency aims achieved

5.4 Discussion

The concept of intervention intensity has received limited empirical consideration to date (Barnett et al., 2004; Duhon et al., 2009; Hale, 2009; Mellard et al., 2010) despite agreement among researchers that intervention dose should be a critical variable for consideration, with implications for applied experimental research (Lipsey & Hurley, 2009) and for applying interventions in educational settings (Codding et al., 2011). Specification and quantification of intensity should be incorporated into research studies investigating the effectiveness of interventions focused on increasing fluency with academic skills (Duhon et al., 2009; Barnett et al., 2004) and should be done in such a way that allows for comparisons across interventions.

The aim of this research was to identify variables associated with intervention dose which were most significantly associated with scores on outcome measures in order to add to the literature on how best to quantify intensity. Results indicate that the number of minutes for which participants are exposed to intervention demonstrates a stronger correlation with such measures. Number of minutes of intervention received was significantly associated with the achievement of fluency aims and with larger increases in scores on the Mathematics Fluency subtest of the WJIII and on measures of fluency with instructional materials and endurance. The number and frequency of sessions per week demonstrated smaller associations with changes in scores on Mathematics Fluency (WJIII) only.

The current findings indicate that in order to quantify intensity of frequency-building interventions, it is beneficial to account for number of minutes exposed to intervention rather than number or frequency of sessions implemented. Many research studies targeting fluency with mathematics skills refer only to the number of sessions implemented. Codding et al. (2011) conducted a meta-analysis of mathematic fact fluency interventions investigating the extent to which intensity impacted treatment effectiveness. They quantified intervention intensity as the total number of sessions implemented within each study. The authors reported difficulties with interpreting data based on the omission of information detailing the number of minutes of intervention received per session.

Inconsistent quantifications of intensity across research studies results in difficulties when comparing the effects of different interventions and in understanding the context of participants' "responsiveness to intervention" (Duhon et al., 2009). Results of the current research indicate that intensity or intervention dose should be quantified by minutes of intervention received. Further, such information should be included in all research studies to allow for comparisons and replication of experimental evaluations of the impact of interventions on participants' response to interventions.

The number of timings implemented with participants was not significantly correlated with the number of fluency aims achieved or changes in scores on any outcome measures. Intensive instruction has been associated with the number of opportunities to respond (Fuchs & Fuchs, 2001; Mellard et al., 2010) and higher rates of correct responding have been shown to be associated with more opportunities to respond (Hale, 2009). Further, active student responding has been associated with increased academic achievement (Sterling, Barbetta, Heron & Heward, 1993; Cavanaugh, Heward & Donelson, 1996). For this reason, the number of timings implemented with participants was purported to correlate with their ability to make gains on outcome measures. However, no significant correlations between timings and outcomes of the intervention were found in this study.

Codding et al. (2011) suggest that several elements can be included within interventions targeting fluency with mathematics skills including timed practice, corrective feedback, materials at an appropriate skill level, brief practice opportunities that incorporate modeling, feedback and reinforcement, and self-management of individual practice opportunities. The authors further assert that such elements may not be equally effective and that the efficacy of each is still to be determined. Intervention sessions within the current research involved ET along with corrective feedback, identification of learning problems using the SCC providing a framework for planned programme modification (e.g., opportunities to engage in untimed practice), and the use of a curriculum designed to teach math facts. Further research is necessary to evaluate the most effective components within such interventions.

A small but significant negative correlation was found between the total number of weeks across which intervention was received and changes in scores on the Mathematics Fluency subtest of the WJIII. This finding suggests that participants who were exposed to the intervention for a higher number of weeks made less significant gains from pre- to post-test. However, there was also a significant negative correlation between the number of weeks and the number of minutes of intervention received indicating that within this sample, participants who were exposed to intervention for a higher number of weeks received less minutes of intervention.

Results of the meta-analysis conducted by Codding et al. (2011) revealed similar difficulties in interpreting data from published studies. The authors found large effect sizes for studies that used fewer than 30 intervention sessions and small effect sizes for those who implemented more than 30 sessions. They conclude that this data should not be interpreted to mean that adding intervention sessions reduces effectiveness since an important variable missing from their analysis was the number of minutes per session for which each treatment was implemented. Similarly, results of this study do not imply that participants make fewer gains when exposed to intervention for a higher number of weeks; rather it emphasises the importance of quantifying the intensity of intervention in terms of the number of minutes of intervention received.

Regression analyses conducted to investigate if the intensity of intervention (as quantified by the number of minutes of intervention received) significantly moderated the number of fluency aims achieved during intervention or changes in scores on outcome measures. After controlling for individual differences, intensity did not significantly moderate scores on any of the outcome measures. The results indicate the importance of considering individual differences prior to implementing frequency-building instruction and emphasise the need for careful planning and development of instruction to match student characteristics.

5.4.1 Limitations and Future Directions

Previous research has demonstrated the impact of a higher frequency of sessions on outcomes of intervention (Duhon et al., 2009; Hale 2009). However, results of the current research demonstrated only a small relationship between increased frequency of sessions and larger gains on the Mathematics Fluency subtest of the WJIII. The mean frequency of sessions implemented as part of this study was 1.54 with a maximum was 2.2 per week. Previous research investigating this variable implemented a higher frequency of sessions (Duhon et al., 2009; Hale 2009). This is a fruitful area for further research as the impact of session frequency on an array of outcomes is still unknown.

The number of weeks for which participants were exposed to intervention correlated negatively with the number and frequency of sessions, the number of minutes of intervention received and the numbers of timings to which participants were exposed. Within this sample, participants who were exposed to intervention for the highest number of weeks were exposed to less intensive instruction along the remaining dimensions. Further research is necessary to investigate the impact of number of weeks of exposure to intervention while controlling for the number of minutes of intervention each participant receives.

Given the findings that the number of timings implemented was not significantly correlated with intervention outcomes and that interventions targeting fluency with mathematics skills can include several elements (Codding et al., 2011), component analyses should be conducted to identify the most effective or important components of instruction and the number of components that should be incorporated. Codding et al. (2011) found that fewer treatment components produced negligible effects whereas more components produced a moderate effect size (i.e., the greater the number of treatment components provided, the larger the effect size) indicating that students may benefit more from treatment packages. They further suggest that determining the least intrusive, but most effective, intervention would be beneficial for students and instructors and are more likely to be consistently and accurately implemented.

Regression analyses demonstrated that intensity, as quantified by number of minutes of intervention received, did not predict outcomes of intervention. The current study focused only on intervention dose. Lentz, Allen and Ehrhardt (1996) suggest that a strong intervention contains elements from the research base that are predictive of success. Evaluation of additional variables, related to intensity of intervention, is necessary to inform a model of intensity that might moderate participants' scores on outcome measures. Further, the mean number of minutes of intervention to which participants were exposed in the current study was 459 with a maximum of 780 minutes. Future investigations are necessary to evaluate the ability of more intensive intervention, or a stronger intervention dose, to moderate outcomes of frequency-building instruction.

5.4.2 Conclusion

Intensity of intervention is a concept which has received little investigation in the literature and requires further investigation and examination (Barnett et al., 2004; Duhon et al., 2009; Hale, 2009; Mellard et al., 2010). It is evident from such research that no definitive or consistent explanation of intensity is used or applied consistently across research studies. The issue with quantification of intensity has implications for both research practices and the application of frequency-building instruction within educational settings. Without consistent quantifications, difficulties arise with regards to interpretation of data and comparisons or replications of studies.

In educational settings, the use of instructional methods and curricula which have been empirically validated is recommended (Johnson & Street, 2013). Equally as important is the evaluation of the intensity with which each method must be implemented in order to achieve optimal outcomes. The current research is the first to report findings implicating the importance of reporting and quantifying the number of minutes of intervention received in both the research and in applied settings. Replications of these findings are necessary.

Chapter 6:

General Discussion

6.1 Overview of Research Area and Aims

Behavioural fluency theorists assert that mastery of academic skills should be evaluated in terms of students' ability to emit high rates of accurate responding rather than accurate responding alone. This assertion is based on the findings that monitoring rate of responding as compared to percentage correct is more sensitive to environmental changes (Lindsley, 1991) and can more accurately represent the probability of future occurrences of behaviour (Johnson and Street, 2013). Further, it is proposed that when a student achieves a fluent performance, critical learning outcomes will occur as a result (Binder, 1996; Brady & Kubina, 2010). Such assertions have been investigated primarily in educational settings with a paucity of findings to support them recorded in the professional literature (Lindsley, 1990). More rigorous, empirically-based research is necessary to validate each critical outcome in relation to attainment of fluent performances (Weiss et al., 2010). The current research sought to investigate critical outcomes, namely; endurance, stability and application, to evaluate the impact of fluent performances on critical learning outcomes.

Johnson and Layng (1994) assert that cumulative fluency-based instruction with component academic skills represents the most effective and efficient method of instruction. Accuracy with component skills is purported to be insufficient to progress proficiently through a curriculum (Haughton, 1980). More recent research has identified a link between overall mathematical ability and fluency with component mathematics skills (Carr & Alexeev, 2011; Carr et al., 2008). The current research sought to evaluate the impact of building fluency with component mathematics skills on standardised measures of mathematical ability.

In terms of the application of fluency-based instruction in educational settings, a need for empirically validated interventions has been identified (Codding et al., 2009; Poncy et al., 2013). Within the current research, implementation of frequency-building instruction, using the Morningside Mathematics Fluency: Math Facts (Johnson & Street, 2008) curricula, was evaluated with a total of 85 participants from the first to the sixth grade. This evaluation was conducted in an effort to contribute to the literature seeking to empirically validate fluency-based instructional procedures and to evaluate moderating variables within the context of their ability to impact students' scores on outcome measures. Findings are discussed in terms of their ability to inform best practice in educational settings.

6.2 Summary of Thesis Findings

Chapters 2 and 3 employed between-group designs to evaluate the effects of frequency-building using the Morningside Mathematics Fluency: Math Facts (Johnson & Street, 2008) curricula. Additionally, in Chapter 3, PT was applied to measure and monitor rates of correct responding with target mathematics skills on a daily basis. The impact of each intervention was evaluated with respect to dependent measures of fluency with targeted skills, critical learning outcomes associated with fluent performances and scores on standardised norm-referenced measures of mathematical ability. Between-group comparisons were employed to assess if the Experimental Group in each study achieved statistically significantly higher scores on each measure at post-testing using pre-tests as a covariate.

Chapter 2 implemented frequency-building instruction, using the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum, with participants in the fourth and fifth grade. Fourteen participants received the intervention and TAU, while fourteen participants in the comparison group received

TAU alone. Participants in the Experimental Group were placed at the beginning of the curriculum and subsequently received frequency-building sessions to increase fluency with component mathematics skills targeted within the curriculum. Ten participants achieved all 26 fluency aims (with 12 fact families) targeted for intervention, while the remaining four achieved between 12-24 fluency aims (with between 5-12 fact families).

Between-group analyses demonstrated statistically significant differences between groups on measures of fluency with targeted skills, critical learning outcomes namely, endurance and stability and on the Mathematical Reasoning subtest of the WIAT-II. The Experimental Group achieved higher scores than the Control Group for each measure. Composite scores of mathematical ability on the WIAT-II increased marginally for the Experimental Group and decreased marginally for the Control Group.

Despite statistically significant differences between groups on measures of performance (as measured by rate of correct responding) for both endurance and stability tests, there were no differences on measures of observed on-task behaviour for the same tests. With regards to measures of application, the Experimental Group performed only marginally better than the control at post-tests. There were also no significant differences between-groups on the Numerical Operations subtest of the WIAT-II. The social validity of frequency-building instruction was also assessed with 81% of the participants in the Experimental Group in Chapter 2. In general, the group stated that they had enjoyed taking part in the intervention and achieving their fluency aims, and that they had benefited from taking part.

Chapter 3 evaluated the effects of frequency-building, using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum, with participants in first and second grade. Twenty-four participants received the mathematics intervention and TAU, while eighteen participants were assigned to an alternative treatment (frequency-building with reading component skills) and received TAU with mathematics. Since the measure of application used in Chapter 2 was not sensitive to changes in rate of correct responding with component skills, this measure was changed. The Morningside Whole Number Computation: Addition and Subtraction (Johnson & Melroe, 2006) curriculum is synchronised with Morningside Math Facts: Addition and Subtraction (Johnson, 2008); therefore, computation problems from this curriculum were used to evaluate application. Further, only measures of performance (i.e., rate of correct responding) were used to evaluate endurance outcomes for each participant as opposed to systematic observations of on-task behaviour. The WJIII replaced the WIAT-II as the standardised measure of mathematical ability since unlike the WIAT-II it included a subtest of Mathematics Fluency.

Variability in the number of fluency aims attained, and the rate at which they were achieved, was observed in Chapter 2. For this reason, PT was applied within Chapter 3 to record and monitor daily frequencies with target mathematics skills and facilitate data-based decisions regarding each participant's progress. Further, the system by which reinforcement was applied was changed so that the schedule and magnitude of reinforcement could be increased. Reinforcement, in the form of "checks" on a chart, was explicitly made contingent on correct responding, increasingly higher rates of correct responding and for achieving fluency aims. Data displayed on SCCs demonstrated increases in rate of correct responding with targeted mathematics and reading skills. However, variability in the number of fluency aims achieved across participants was observed similar to the findings in

Chapter 2. Further, a lower mean number of fluency aims achieved, as a result of intervention, was also observed as compared with Chapter 2. The Mathematics Group were exposed to 22 sessions of frequency-building instruction and achieved a mean of 3.6 (range: 0-15) fluency aims. The Reading Group were exposed to the same intensity of instruction and achieved a mean of 2.9 (range: 0-9) aims.

Between-group analyses demonstrated significant differences on measures of endurance and application with mathematics skills. The Mathematics Group scored significantly higher on measures of both critical learning outcomes. Similarly, the Reading Group scored significantly higher than the Mathematics Group on measures of endurance with reading skills at post-testing, but not on measures of application. Significant differences between groups on mathematics and reading subtests of the WJIII were not found. However, scores on the Mathematics Fluency subtest significantly increased from pre- to post-testing for the Mathematics Group but not for the Reading Group, suggesting that a more intensive intervention may have yielded more significant results on standardised measures of ability.

The findings in Chapters 2 and 3 demonstrated variability in participants' response to frequency-building instruction, even with the addition of PT. The variability in the number of fluency aims achieved across both studies indicated that additional variables moderated the outcomes of each study. In Chapter 2, the four participants who achieved the lowest number of aims also demonstrated pre-test scores of mathematical ability of between 66 (extremely low) to 92 (average) and pre-tests scores of fluency with targeted skills of between 3-11 correct responses per-minute (below the average of the group) indicating mathematical ability and fluency with instructional materials as potential moderators of the intervention. A lower mean number of fluency aims was achieved by participants in Chapter 3.

Participants within this study consisted of a younger sample of students (first and second grade) indicating that age, grade and an associated lower processing speed ability may have moderated their ability to achieve fluency aims as outlined by the curriculum.

Previous research has also noted variability in the outcomes of fluency-based instruction (Bliss et al., 2010; Miller et al., 2011). Individual differences in pre-test fluency, prior to implementing fluency-based instruction, have been implicated as a moderator of such instruction (Burns et al., 2010). Research has also found an association between the ability to perform tasks fluently and age and school grade (Kavé, 2006; Sak & Maker, 2006), a relationship between processing speed ability and math fact fluency (Chong & Siegel, 2008) and gender differences in mathematics fluency (Carr et al., 2008; Royer et al., 1999).

Chapter 4 comprised of two studies to investigate the ability of individual differences to moderate the impact of frequency-building instruction. Given the variability in response to intervention found across Chapters 2 and 3, and findings in the literature, Study 3 in Chapter 4 examined participant age, grade, gender, pre-test scores on standardised measures of ability (WJIII) and pre-test assessments of fluency with instructional materials in relation to their ability to moderate the outcomes of frequency-building instruction. Analyses were conducted with 71 participants from first to sixth grade who had received frequency-building instruction using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum. Regression analyses demonstrated the ability of participant age and pre-test levels of fluency to moderate the outcomes of frequency-building instruction. Kruskal-Wallis tests also found statistically significant differences on outcome measures across first to sixth grade, with higher grades achieving higher scores on outcome measures. Social validity of frequency-building instruction was also assessed during this study with 63% of the sample. The majority of participants responded that they thought the instructional goals (i.e., mathematics skills) targeted during intervention were important, that they enjoyed the procedure and that it helped with their work in class.

The findings in Study 3 of Chapter 4 found that participant age moderated the effects of frequency-building. Younger participants, with assumed lower processing speed abilities, achieved less fluency aims than older participants, despite demonstrating accuracy with targeted skills. Study 4 in Chapter 4 investigated processing speed ability with fourteen participants in fourth grade. The Processing Speed Index of the WISC-IV was conducted pre-intervention and evaluated in relation to participants' achievement of fluency aims during intervention. A large positive correlation between pre-test PSI and number of aims achieved was found indicating that processing speed ability is strongly associated with the ability to achieve fluency aims within the context of frequency-building instruction.

Chapter 5 examined the intensity of frequency-building instruction using the same sample of 71 participants as in Study 3 of Chapter 4. Findings in Chapter 2 and 3 had also implicated intensity as a factor which may have moderated outcomes of intervention. Specifically, Chapter 2 demonstrated that composite mathematics scores on the WIAT-II increased marginally for the Experimental Group and decreased marginally for the Control Group. The Experimental Group also performed marginally better on measures of application at post-testing. Within Chapter 3, scores on the Mathematics Fluency subtest of the WJIII were higher for the Mathematics Group than for the Reading Group at post-testing. However, the differences in scores were not large enough to yield a statistically significant difference between groups. Such differences at post-testing observed in both Chapter 2 and 3 implied that the intervention may have impacted outcome measures but that the intensity of each intervention possibly moderated effect sizes.

Intervention intensity is a concept which has received very little empirical examination to date. Prior to investigating the impact of intensity on outcomes of intervention, it is necessary for research to focus on defining and quantifying the concept (Duhon et al., 2009). For this reason, Chapter 5 investigated different "dose" related dimensions to ascertain if varying levels of each dimension were significantly associated with scores on outcomes measures. Results indicated that the number of minutes of intervention implemented with participants demonstrated the strongest correlations with outcome measures. However, regression analysis demonstrated that after controlling for the effects of individual differences, intensity (as measured by the number of minutes of intervention received) did not significantly moderate the outcomes of intervention.

6.3 Theoretical and Applied Implications

The current thesis has contributed to the literature on behavioural fluency with important implications for both theory and the application of fluency-based instruction. Critical learning outcomes associated with fluent performances were examined using experimental designs, analyses and sample sizes not previously reported in the literature. A potential link between fluent performances of component skills and general mathematical ability was also examined. The direct impact of frequency-building with such skills on general mathematical ability has been examined in few research studies to date so that the current findings are a significant addition to the literature.

The current findings have further important implications for educational settings. Mathematics is a core component of the educational curriculum. The level of proficiency achieved by students within this academic domain can significantly impact independent functioning in society (Geary et al., 2012) and future performances across many academic and applied skills. Fluency with component mathematics skill is purported to be essential to achieve proficiency within this academic domain (Binder, 1993). Despite this, the necessity for, and paucity of, empirically validated procedures and curricula for building fluency with mathematics skills has been noted in the literature (Codding et al., 2009; Poncy et al., 2013). The current research empirically examined curricula and procedures designed to build fluency with component mathematics skills. Investigations of such procedures, within the current thesis, have provided evidence for the benefits associated with their incorporation into mathematics instruction in educational settings.

Equally as important is the investigation of moderators of such instruction. Identification of individual differences which significantly impact students' response to frequency-building instruction facilitates the development and implementation of interventions for individual students (e.g., for deciding the appropriateness of fluency-based instruction and for selecting appropriate fluency aims). Results of Chapter 4 highlight the importance of considering such variables for instruction. Additionally, the ability of intensity, or intervention dose, to moderate outcomes, after controlling for individual differences, was not significant further emphasising the necessity to match instruction to student's needs in order to achieve best outcomes. The following sections discuss theoretical and applied implications of the current research findings in more detail.

6.3.1 Critical Learning Outcomes

Critical learning outcomes investigated within this thesis included endurance, stability and application. Endurance is described as the ability to engage in a skill for prolonged periods without fatiguing (Fabrizio & Moors, 2003). Proponents of behavioural fluency purport that the ability to maintain proficient performance over extended durations of time is typically not achieved until a minimum level of speed and accuracy with such skills has been attained. Brady and Kubina (2010) note that research investigating critical outcomes to date focuses primarily on application and retention with fewer examinations of endurance reported in the literature. Findings within the current thesis represent a significant contribution to the literature in this area. Participants who received frequency-building with mathematics skills demonstrated the ability to maintain higher rates of correct responding over increased durations of performance. This finding indicates that building fluent performances results in the ability to endure and, as such, is consistent with the behavioural fluency literature.

Stability has been described as performance in the presence of distracting stimuli (Johnson & Layng, 1992). Similar to endurance, the ability to maintain proficient performance in this condition is purported to improve when skills can be performed fluently. To date, no empirical investigations of this outcome have been reported in the literature. The current findings provide evidence for improvements in stability once fluent performances are attained. Participants who achieved fluency with mathematics skills were able to maintain higher rates of correct responding than control participants when in the presence of environmental distractors.

The current findings also add to the literature with respect to the measurement of endurance and stability. Although systematic observation of on-task behaviour has been employed to assess endurance in previous research, measures of performance (i.e., rate of correct responding) were found to be more sensitive to the effects of building fluency both endurance and stability. Statistically significant differences between groups were found for measures of performance during tests of endurance and stability; however, no differences were found for systematic observations of on-task behaviour. This indicates that measures of performance are a more sensitive measure of such outcomes as opposed to observing physical topographies of on-task behaviour.

The ability to improve learners' performance over extended durations, and in the presence of distracting stimuli, has significant implications for practice. Such findings provide the opportunity to positively affect learning (Brady & Kubina, 2010) by incorporating fluency-based instruction within educational settings. In particular, Binder et al. (1990) suggests that behavioural definitions of endurance may be a parsimonious approach to investigating and intervening on "attention span" rather than attempting to explain it through complex cognitive processes. In doing so, interventions for students with attention deficits could focus on increasing endurance by incorporating fluency-based instruction.

Relative to endurance and stability, application has been investigated to a greater extent. However, additional research is warranted to provide evidence of improvements in this outcome once fluent performances are attained. The current findings report mixed results for this critical outcome. Significant improvements in tests of application were found for the Mathematics Group in Chapter 3, supporting the assertion that improvements in the ability to apply component skills occur, once fluent performances were attained. However, the findings in Chapter 2 did not support this assertion. Issues regarding the measurement of this may have contributed to the inconsistent findings. Further research is warranted to replicate the findings of Chapter 3 and to determine consistent and valid measures of this outcome.

Finally, the importance of experimental control and the use of between-group analyses were highlighted in both Chapter 2 and 3. Increases in scores on some measures of critical outcomes were found for both Experimental and Control groups from pre- to post-tests indicating that extraneous variables may have contributed, in part, to such increases (e.g., TAU, treatment interference). For this reason, between-group analyses are preferable to investigate such outcomes, so that a significant functional relationship can be demonstrated between attainment of fluent performances and subsequent improvements on measures of critical outcomes.

6.3.2 General Mathematical Ability

Within the area of behavioural fluency, researchers propose that building fluent performances with component academic skills affects overall achievement within that academic domain (Binder, 1996; Haughton, 1980; Johnson & Street, 2013) and that fluent component repertoires facilitate the acquisition of further, more complex skills. Additionally, research investigating the importance of fluency with component mathematics skills has identified a link between overall mathematical ability and fluency with such skills (Carr & Alexeev, 2011; Carr et al., 2008). The current research adds to the literature proposing links between building fluent performances with component mathematics skills and subsequent performances on tests of general mathematical ability.

The findings in Chapter 2 found statistically significant differences on scores of the Mathematical Reasoning of the WIAT-II demonstrating that frequency-building component skills impacted participants' performance on this measure.

Although overall composite scores for mathematical ability were not significantly different between groups at post-test, scores for the frequency-building group increase marginally while scores for the control group decreased to a similar degree. A mean of 23.4 frequency-building sessions, approximately 20 minutes in duration, had a significant impact on standardised measures of ability. No statistical differences were found between groups on mathematics subtests of the WJIII in Chapter 3. However, there were significant increases in scores on the Mathematics Fluency subtest for the Mathematics Group only suggesting that frequency-building may have impacted this measure.

To date, few studies have investigated the ability of such interventions to impact standardised scores of mathematical ability. Codding et al. (2009) report their results of a meta-analysis investigating fluency-based instruction with mathematics skills, noting that very few studies examine associated generalised effects. The findings in Chapters 2 and 3 contribute considerably to the current literature in this area and provide a significant rationale for the promotion of fluent component repertoires to improve general mathematical ability.

6.3.3 Building Fluent Performances

Researchers suggest that promoting accuracy *and* fluency with mathematics skills should be a focus of instruction in primary school years (Carr & Alexeev, 2011); however, sufficient opportunities to practice such skills are not provided within educational settings (Codding et al, 2010). Since a gap in the research exists with respect to empirical validation of fluency-based instruction (Codding et al., 2009; Poncy et al., 2013), the findings of the current thesis contribute to the literature with important implications for applied settings.

Positive outcomes have been reported within informal evaluations of the Morningside Mathematics Fluency: Math Facts (Johnson, 2008); however, experimental evaluation of their efficacy has not been reported to date. Frequency-building using the Morningside curricula were evaluated with 85 participants within this thesis. Chapter 2 demonstrated the ability of frequency-building, using the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum, to increase rate of correct responding with targeted mathematics skills, with participants in fourth and fifth grade. Frequency-building using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum was successful in building fluent performances in Chapters 3 and 4, with participants ranging from the first to sixth grade. While continued research should be conducted to further validate each curriculum, the current findings provide evidence for their efficacy and provide sufficient rationale to incorporate each curriculum into educational settings, to increase fluency with such component skills.

Social validity questionnaires exploring frequency-building instruction from participants' perspective were also examined for 66% of the total sample who took part. Questionnaires incorporated questions regarding the importance of the goals of instruction and their view of the procedures and effects. Results of this examination showed that the majority of participants enjoyed taking part in frequency-building instruction and were motivated to achieve their fluency aims. This is an important implication for the application of frequency-building procedures with students in educational settings, in that students are motivated to engage in this type of instruction. It is suggested that low rates of responding when completing mathematics tasks, within set time limits, can be associated with receiving no contingent reinforcement, delayed or less frequent reinforcement as a consequence of infrequently completing such tasks (Bliss et al., 2010; Logan & Skinner, 1998; Skinner, 2002). This, in conjunction with a high level of response effort, is purported to decrease the probability that students engage in mathematics tasks (Billington et al., 2004; Bliss et al., 2010; Skinner et al., 2005). Frequency-building instruction incorporates positive reinforcement contingent on higher rates of correct responding following each timing, which may increase students' probability to engage. Positive views of the interventions implemented in the current research are consistent with this.

6.3.4 Moderators of Frequency-Building Instruction

Although frequency-building instruction with each curriculum demonstrated efficacy in relation to building fluent performances, variability in the ability to, and the rate at which, participants achieved fluency aims was also demonstrated. Further, younger participants (first and second grade) in Chapter 3 achieved less fluency aims as compared to those who took part in Chapter 2 (fourth and fifth grade). Such findings indicate that outcomes of frequency-building instruction can be moderated by additional variables and careful planning and development of such instruction is warranted. Examination of such variables in Chapters 4 and 5 determined important findings for practice. The following sections provide an overview of implications arising from the current findings in relation to applying frequency-building instruction in educational settings.

6.4.4.1 Screening

The importance of matching instruction to each student's needs and abilities has been emphasised in the literature (Burns et al., 2010; Burns et al., 2006; Mong & Mong, 2012). Burns et al., (2010) maintain that student outcomes such as task completion, task comprehension, time on task and learning growth significantly increase when task demands represent an instructional level for mathematics. In order to facilitate such individualised instruction, sampling of students' fluency with instructional materials is recommended to ascertain the appropriateness of fluency-based instruction for each student (Burns et al., 2010). However, few studies have examined the consistency with which such measures can be used to guide instructional programming (Burns et al., 2006).

Chapter 4 demonstrated the ability of pre-test levels of fluency to moderate such instruction and as such, supports the recommendation that pre-test levels of fluency be sampled prior to implementing fluency-based instruction. Specifically, with regards to the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum, pre-intervention sampling of fluency levels with students should inform instructors of the appropriateness of building fluency with this curriculum for each individual student. Continued research is necessary to ascertain specific levels of pre-intervention fluency necessary to progress through a frequency-building intervention using this curriculum.

The current findings indicate that students who achieved a lower number of fluency aims during intervention presented with lower levels of fluency pre-intervention and as such may have benefited from instruction focusing on acquisition initially. Martens and Witt (2004) describe the Instructional Hierarchy (IH) for teaching academic skills. Using the IH as a guide for instruction, skills are taught at the level of proficiency with which they are performed. Learning at each stage of the hierarchy is promoted in different ways. The first stage of the hierarchy targets acquisition using such approaches as modelling, prompting and error corrections and uses accurate responding alone as a measure of mastery. The second phase targets fluency with rate of accurate responding as a measure of mastery. Since different instructional approaches are used within each phase, knowing how well a student performs a skill facilitates the selection of the most effective teaching strategy for that level (Daly et al., 1996). The findings in Chapter 4 are consistent with this approach to teaching and suggest that sampling levels of fluency with the curriculum could facilitate in selecting acquisition or fluency interventions for each individual student.

Findings of the current research also support a Response to Intervention (RTI) framework of instruction and assessment. RTI emphasises differentiated instruction based on differing educational needs of students and achieves this by screening and monitoring students using meta-level assessments of ability. The results of Chapters 2 and 3 provide evidence of the difficulties in impacting standardised norm-referenced assessments of academic ability as outcome measures of instruction with component academic skills. Additionally, Chapter 4 determined that scores on the same assessments are not predictive of progression through such instruction. These findings support the use of meta-level assessments for both assessing outcomes of intervention and informing the development and implementation of frequency-building instruction. They further suggest that such assessments should be used in educational settings in conjunction with norm-referenced assessments.

6.4.4.2 Age, Grade and Processing Speed

The importance of considering student age, grade and level of processing speed ability was also demonstrated in Chapter 4. Specifically, such factors are important when considering again, the appropriateness of fluency-based instruction for individual students and when determining fluency aims. The IH provides an approach to instruction which allows acquisition of skills, followed by a focus on building fluency. Once acquisition mastery criteria are met, fluency is targeted. Findings in Chapter 4 are consistent with this approach to instruction; however, participant age, grade and processing speed ability were also implicated as factors which should be considered before focusing on building fluency.

Heikkilä et al. (2013) describe the process of "automatisation", or fluency, with reading skills as gradual and developmental rather than being an "on/off" skill. This suggests that student age plays a role in developing fluency with such skills. Findings in Chapter 4 suggest that the process of achieving fluency with mathematics skills may also be impacted by age so that, once accurate responding is achieved, age should still be considered when moving to the fluency phase of instruction as outlined by the IH. Within the current research, a number of younger participants demonstrated accurate responding with mathematics skills targeted in the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum; however, they did not achieve the same number of aims as older participants within the sample.

In addition to considering such variables when determining the appropriateness of fluency-based instruction, the findings in Chapter 4 have further implications for the selection of appropriate fluency aims. Gross et al. (2013) emphasise the importance of setting goals or aims, in that the attainment of such aims reinforces behaviours. The authors further assert that improvements in academic performance may be a result of goals that are attainable in conjunction with feedback and reward procedures. It follows that in order to develop the most effective frequency-building instruction, fluency aims should be determined in such a way as to be achievable by each individual student. The significant relationships found between participant age, grade and processing speed ability and the achievement of fluency aims, indicate each should be considered when selecting appropriate fluency aims for students within frequency-building interventions.

Further research is necessary to investigate the best methods for determining attainable fluency aims. However, the current research indicates that such aims should be differentiated by age as opposed to recommending one fluency aim for each skill based on sampling with groups of fluent learners. Measurement of processing speed ability, when planning frequency-building instruction, could potentially facilitate the selection of appropriate fluency aims for individual students. In this way, individual differences in processing speed can be accounted for prior to setting fluency aims for each student. This may be particularly beneficial when implementing frequency-building instruction with students with diagnoses associated with deficits in processing speed ability.

6.3.4.3 Intensity of Instruction

Intervention intensity has been emphasised as a critical variable to consider when planning and implementing those interventions (Codding et al., 2011). Despite this, few studies have evaluated intensity relative to its ability to moderate effectiveness of interventions. Perhaps more importantly, the definition and quantification of this concept is inconsistent throughout the literature. Chapter 5 sought to contribute to the literature with respect to quantification of intensity, specifically in relation to intervention dose, and to examine intensity as a moderator of frequency-building instruction.

The results of Chapter 5 showed that the number of minutes for which participants were exposed to intervention demonstrated the strongest relationship with scores on outcomes measures. Although further research is necessary to best quantify intensity, such findings suggest that the number of minutes participants are exposed to intervention should be reported consistently throughout research studies investigating frequency-building interventions. The omission of such information can cause issues when interpreting data and conducting comparisons of interventions reported in the literature (Codding et al., 2011).

The quantification of intensity and consistent reporting throughout the literature has further significant implications for application of frequency-building instruction. Practitioners in educational settings should be aware of the intensity with which instruction should be implemented in order to achieve expected outcomes. This information facilitates the incorporation of instruction into educational settings most effectively and provides information on the feasibility of such instruction within each setting.

Analyses conducted to examine intensity as a moderator of frequency-building instruction found that intensity, as quantified by number of minutes intervention, did not moderate the outcomes of this intervention after controlling for individual differences. This finding further emphasises the importance of considering individual differences prior to implementing intervention. Johnson and Street (2013) maintain that careful planning and development of intervention is equally as important as providing it at a high intensity. The findings in Chapter 5 support this recommendation and imply that increasing intensity will not impact the effects of an intervention unless careful planning is conducted, to match instruction to student characteristics and abilities.

6.4 Limitations and Future Directions

A number of limitations and future directions have been discussed throughout this thesis. The following section elaborates on these limitations, highlighting directions for future research.

6.4.1 Impacting Standardised Norm-Referenced Assessments

The impact of frequency-building, using the Morningside Math Facts: Multiplication and Division (Johnson, 2008) curriculum, on a subtest of the WIAT-II is a significant finding in Chapter 2. However, the impact on the composite score for overall mathematics ability was not statistically significant. Further, statistically significant results were not found in relation to the ability of the intervention to impact norm-referenced assessments in Chapter 3. Such assessments can be insensitive to interventions targeting only one key component skill. Lipsey and Hurley (2009) discuss the sensitivity of dependent measures to the effects of applied experimental research and note that, for measures to respond to the effects of intervention, valid measures of the characteristic that the intervention is expected to change must be used. Thus, measures of general mathematical ability, which do not measure the specific skill expected to change alone, will be more difficult to impact.

Lipsey and Hurley (2009) further note the impact of irrelevant variation associated with individual differences on dependent measures. They explain that if a measure is responsive to individual differences with skills not related to intervention, variability in responding on such skills can obscure gains obtained during intervention. They further suggest the use of “edumetric” assessments – measures developed through sampling the content domain representing the new responses which participants are expected to acquire through intervention. Such “edumetric” assessments are more sensitive than psychometric tests to changes obtained from intervention. In line with this, Johnson and Street (2013) describe the use of meta-level assessments to evaluate the impact of academic instruction. Such assessments measure performance on a subset of skills that best predict mastery of related skills (i.e., they typically measure mastery of component skills which are pre-requisites to mastery of composite repertoires that norm-referenced assessments may measure). The inclusion of such measures would be beneficial in future investigations of frequency-building instruction.

In relation to impacting measures of general ability on norm-referenced assessments, future studies should investigate the impact of longitudinal interventions assessing generative instruction and behavioural fluency which target a greater number of component skills for frequency-building instruction. The current research investigated the impact of frequency-building with only one component skill necessary to attain a proficiency in this domain. Instruction with a larger number of skills, which standardised norm-referenced assessments measure, is more likely to impact on such measures.

6.4.2 Investigation of Critical Learning Outcomes

Investigations of critical learning outcomes are reported infrequently within the behavioural fluency literature. While the current research represents a significant addition to the empirical evaluation of critical outcomes associated with fluent performances, further research is warranted to replicate and investigate each outcome further. Since definitions of critical learning are inconsistent throughout the behavioural fluency literature, further research is necessary to more precisely define each outcome and develop standardised definitions to allow for consistent measurement. An examination of retention and generativity were beyond the scope of this thesis. The abilities to retain and combine skills to form new more complex skills are important goals of any instruction. It follows that future research studies should investigate such outcomes further.

Although investigations of endurance, stability and application yielded significant results, further investigations are warranted. In particular, research is warranted to more precisely define how each should be measured. The current research demonstrated that measures of performance were more sensitive to systematic observations of on-task behaviour thus adding to the literature on how best to measure endurance and stability. Specific to stability, future research should further investigate the incorporation of environmental stimuli to represent distraction. Previous research investigating distractors, from a cognitive perspective, differentiate distractors in terms of their form e.g., auditory and visual (Singer et al., 1991) and have demonstrated that performance of tasks may be more impaired when distractors are congruent with the task being performed (Sreenivasan & Jha, 2007). More specific investigations and comparisons of distracting stimuli within the behavioural fluency research should contribute to a better understanding of stability and subsequent implications for students achieving fluent performances. Such research would be particularly beneficial for students with diagnosed attentional deficits.

With respect to tests of application, the current findings were mixed in relation to the impact of frequency-building on this outcome. Two reasons why such results were found may be beneficial to future investigations. The first is related to its measurement. The change in test of application from Chapter 2 to Chapter 3 found that measures which are more closely aligned with component skills performed fluently were more sensitive to improvements on this outcome. Application tests that require a greater number of skills to complete may affect the impact of teaching only one of those skills fluently.

A second and related reason why the impact of intervention may not have been as large for tests of application is related to the differentiation between composite and drill practice. Drills involve the practice of isolated items while composite practice requires the use of learned component responses in combination (Codding et al., 2010). The findings in Chapter 2 and 3 indicate that a more valid test of application when examining the effects of drill practice alone should be one which is closely aligned with skills targeted during intervention and should be incorporated in future similar studies. Further, composite practice has been identified as an important component of effective instruction (Codding et al., 2010; Johnson & Layng, 1994; Martens & Witt, 2004). Since the Morningside Mathematics Fluency: Math Facts (Johnson, 2008) curriculum is designed to conduct drill practice with target mathematic skills, the current study investigated drill practice only in relation to its impact on application. Future research is necessary to investigate the impact of composite practice and to compare the benefits of both types of practice on intervention outcomes.

6.4.3 Investigation of Intensity

With respect to the investigation of intensity in Chapter 5, only variables related to intervention dose were investigated in terms of quantifying intensity and evaluating its impact on outcomes of the intervention. Additional elements of intervention, supplementary to those related to dimensions of time and frequency have been suggested in the literature as related and significant to intensive instruction. Such elements include instructional group size (Barnett et al., 2004; Mellard et al., 2010), immediacy of corrective feedback, mastery requirements of the content, number of transitions among contents, the specificity of curricular goals and instructor speciality and skills (Mellard et al., 2010). The suggestion that intensity is a concept broader than that of variables describing intervention dose, in conjunction with the finding that individual differences impacted outcomes of intervention to a greater extent than the number of minutes of exposure to intervention, implies that such elements warrant further investigation to further quantify the concept of intervention intensity.

Within the current investigation, both individual differences and intervention dose were investigated within the same sample of participants. The significant impact of individual differences may have affected findings related to the ability of intensity (as defined by number of minutes of intervention) to moderate outcomes of intervention. Future studies, investigating intervention dose alone, should consider such individual differences and use screening procedures to form homogenous groups for between group comparisons of differing levels of intervention dose. Further, the maximum number of minutes any participant was exposed to frequency-building within Chapter 5 was 780 minutes. Lipsey and Hurley (2009) maintain that the stronger the intervention dose that is applied during intervention, the larger the response should be if the intervention is effective with a specific sample. Although issues can arise in terms of implementing academic interventions at high intensities within applied settings (e.g., absenteeism, school holidays), future research should also investigate intervention dose at a higher intensity than that implemented within the current research.

6.4.3 Experimental Design

Limitations in relation to the design of Chapter 3 arose with respect to the inclusion of a control group who received an alternative intervention. Intervention targeting fluency with academic skills was implemented with both groups; however, the control group received instruction with component reading skills. Scores on tests of endurance with mathematics and application were seen to increase for both groups suggesting that treatment interference possibly affected post-test measures. The addition of a TAU control group should be incorporated within future studies or an alternative intervention which does not target fluent performances. The increase in rate of correct responding demonstrated by the Reading Group further implies that future research should investigate the generalised effects of fluency-based instruction with respect to its ability to increase speed of responding with skills not targeted in intervention and across academic domains.

6.5 Summary and Conclusion

This thesis represents a comprehensive investigation of procedures and curricula designed to achieve behavioural fluency with mathematics skills, and outcomes associated with building fluent performances. The aims of the current research were to (i) experimentally investigate the efficacy of frequency-building, PT and the Morningside mathematics curricula with large sample sizes, (ii) examine the impact of such instruction on critical learning outcomes associated with fluent performances, (ii) assess for the effects of building fluent performances on standardised measures of mathematical ability, and (iv) identify moderators of fluency-based instruction, specifically individual differences (i.e., age, grade, gender, processing speed and mathematical ability) and implementation variables (i.e., levels of instructional intensity).

Competency in mathematics is pivotal for engaging in many academic and applied skills and is essential to everyday life. Proficiency in this academic domain has been linked to fluent performances of key component skills (Carr & Alexeev, 2011; Carr et al., 2008). However, there are is a paucity of evidence-based interventions available to increase fluent performances with such skills (Codding et al., 2009). The current thesis evaluated frequency-building and PT in conjunction with the Morningside mathematics curricula with 85 participants from the first to sixth grade using between-group analyses. Results demonstrated the efficacy of each intervention, adding significantly to literature examining evidence-based practices for mathematics instruction. Furthermore, outcomes were not only demonstrated across measures of fluency but also across standardised assessments. This has considerable implications for applied settings, since it has been argued that the use of comprehensive and evidence-based programmes for students contribute to the prevention of academic failure (Johnson & Street, 2013).

Equally as important as providing an evidence-base for fluency instruction is the necessity to identify additional variables which may impact or moderate their effectiveness. The matching of instruction to individual students' needs is an essential element of intervention design (Mong & Mong, 2012). Identification of moderating variables will ascertain for whom fluency-based instruction could be most effective and at what intensity of application will certain outcomes be demonstrated. Such findings will inform on how best to plan and design interventions in order to achieve the best outcomes for each individual student. The current findings have contributed significantly to the design of fluency-based intervention for primary school students indicating that the age, grade, processing speed ability and pre-test levels of fluency are vital to consider prior to intervention. Further, the results have informed on how best to quantify and evaluate intensity in order to provide a context for the outcomes of intervention.

The current investigation of outcomes associated with building fluent performances provide a significant rationale for the inclusion of such evidence-based interventions within educational settings. The attainment of fluency was found to improve performances on measures of critical learning outcomes and in some instances scores on standardised assessments of general mathematical ability. Binder (1996) suggested that a vast quantity of research is necessary to address the emergence of critical outcomes for every response class in the human repertoire, so that, simply demonstrating in a systematic fashion that higher performance frequencies improve one or more of the critical outcomes (i.e., endurance, stability, application and retention) for any behaviour class, it is a notable accomplishment. The current findings provide support for the emergence of critical learning outcomes (i.e., endurance, stability and application), for purported improvements in performances on measures of mathematical ability and finally, emphasise the importance of defining mastery in terms of accuracy *and* fluency, rather than accuracy alone.

The thesis adds to the growing body of literature in support of behavioural fluency instruction to achieve true academic mastery. The studies have robustly supported the efficacy of fluency based instructions by employing group designs and standardised measures of assessment. Importantly the thesis also investigates the variables that moderate fluency outcomes, which have not been collectively assessed in the literature to date. The findings in general have significant applied implications for the design and delivery of curricula to promote long lasting positive outcomes in mathematics performance in children.

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Appendix A

Sample of sticker charts used in Chapter 2

Math Facts Goals

Name:

Slice in curriculum	**Goal**	**Goal met**
New Facts 1 (3rd number)	50-60	
New Facts 1 (Fact Sheet)	50-60	
New Facts 2 (3rd number)	50-60	
New Facts 2 (Fact Sheet)	50-60	
Cum 1-2 (3rd number)	60-70	
Cum 1-2 (Fact Sheet)	60-70	
New Facts 3 (3rd number)	50-60	
New Facts 3 (Fact Sheet)	50-60	
Cum 1-3 (3rd number)	60-70	

Appendix B

Samples of Morningside Math Facts: Multiplication and Division

Chapter 2

Name ____________________

Morningside Math Facts Fluency
Multiplication - Division
2 2 4, 2 3 6, 2 4 8

Box Sheet 3

2 2 4
2×2=4
2×2=4
4÷2=2
4÷2=2

2 3 6
2×3=6
3×2=6
6÷2=3
6÷3=2

2 4 8
2×4=8
4×2=8
8÷2=4
8÷4=2

2 4 8
2×4=8
4×2=8
8÷2=4
8÷4=2

2 2 4
2×2=4
2×2=4
4÷2=2

2 3 6
2×3=6
3×2=6
6÷2=3
6÷3=2

Goal 4 - 6 seconds			
	Date	Family	Time
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Goal 4 - 6 seconds				
	Date	Family		Time
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Teacher Verified? Yes No

 1

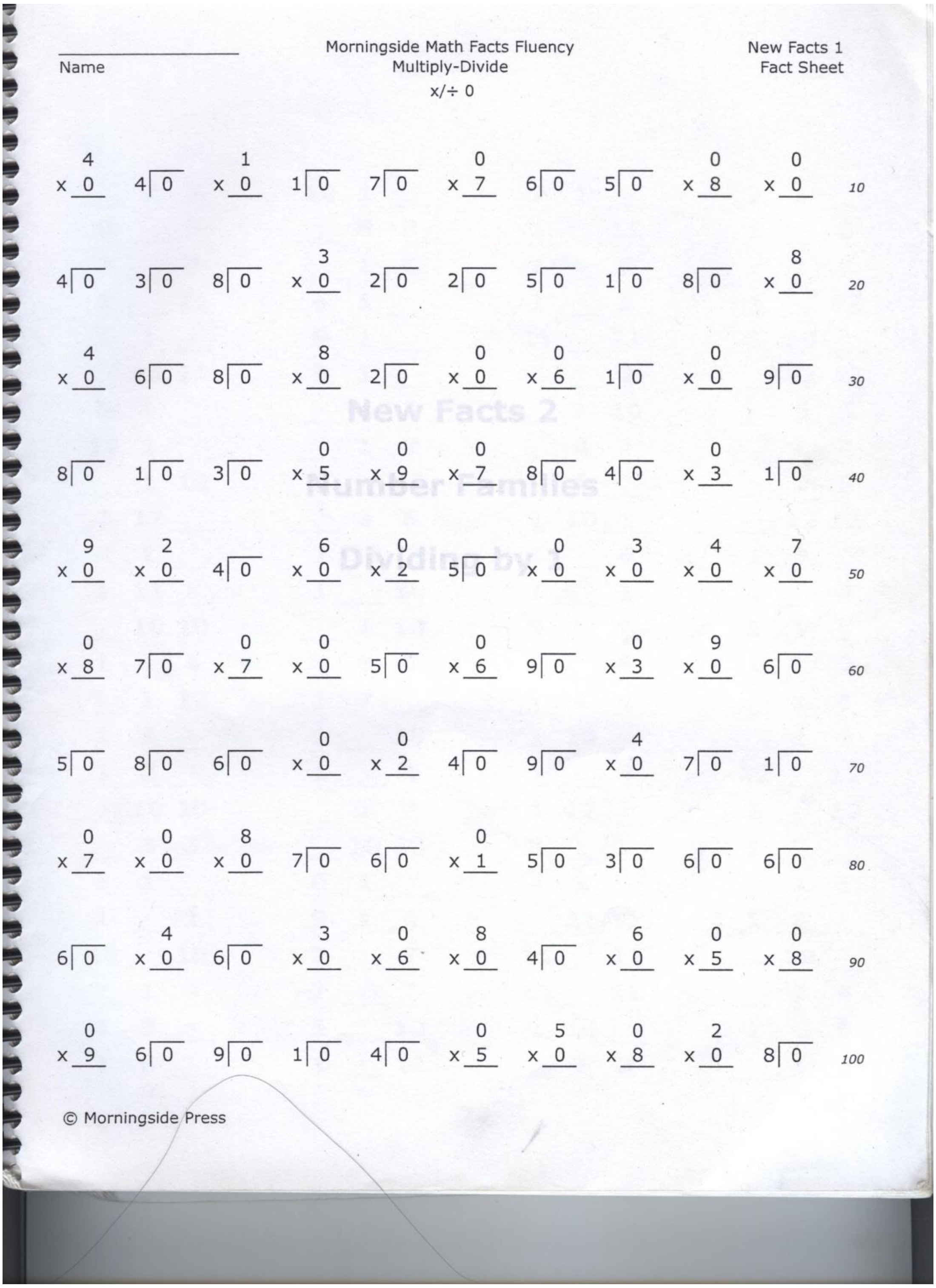
Name ____________________

Morningside Math Facts Fluency
Multiply-Divide

2 2 4, 2 3 6, 2 4 8

New Fact 3
3rd Number

___ 2 6	3 2 ___	2 2 ___	___ 2 6
___ 2 6	___ 4 8	3 ___ 6	___ 4 8
2 ___ 6	3 2 ___	2 2 ___	3 ___ 6
2 3 ___	2 ___ 4	2 ___ 4	___ 2 8
___ 2 8	2 ___ 6	___ 2 4	2 2 ___
2 3 ___	2 2 ___	2 4 ___	___ 2 6
___ 4 8	2 ___ 6	2 ___ 4	4 2 ___
2 2 ___	___ 3 6	2 2 ___	___ 2 4
2 2 ___	___ 3 6	___ 3 6	3 ___ 6
2 2 ___	3 2 ___	___ 3 6	4 2 ___
2 ___ 4	2 2 ___	2 4 ___	4 ___ 8
4 2 ___	___ 4 8	2 ___ 4	4 2 ___
2 ___ 8	2 ___ 6	4 2 ___	___ 2 6
2 2 ___	___ 2 4	3 2 ___	___ 2 8
2 2 ___	___ 2 8	2 ___ 6	2 2 ___
2 2 ___	4 2 ___	4 2 ___	4 ___ 8
___ 2 4	___ 2 4	___ 2 6	___ 2 4
2 ___ 4	2 ___ 4	3 ___ 6	2 3 ___
___ 2 8	___ 2 4	2 2 ___	___ 2 6
___ 2 4	2 2 ___	___ 2 6	2 ___ 6
___ 3 6	4 ___ 8	___ 3 6	3 ___ 6
3 ___ 6	___ 2 6	2 2 ___	2 4 ___
___ 2 6	2 ___ 4	4 ___ 8	2 ___ 4
2 2 ___	2 ___ 6	2 4 ___	2 ___ 4
___ 2 4	2 ___ 6	___ 4 8	___ 3 6
25	50	75	100



Name ________________

Morningside Math Facts Fluency
Multiply-Divide
x/÷ 0

New Facts 1
Fact Sheet

4×0	$4\overline{)0}$	1×0	$1\overline{)0}$	$7\overline{)0}$	0×7	$6\overline{)0}$	$5\overline{)0}$	0×8	0×0	10
$4\overline{)0}$	$3\overline{)0}$	$8\overline{)0}$	3×0	$2\overline{)0}$	$2\overline{)0}$	$5\overline{)0}$	$1\overline{)0}$	$8\overline{)0}$	8×0	20
4×0	$6\overline{)0}$	$8\overline{)0}$	8×0	$2\overline{)0}$	0×0	0×6	$1\overline{)0}$	0×0	$9\overline{)0}$	30
$8\overline{)0}$	$1\overline{)0}$	$3\overline{)0}$	0×5	0×9	0×7	$8\overline{)0}$	$4\overline{)0}$	0×3	$1\overline{)0}$	40
9×0	2×0	$4\overline{)0}$	6×0	0×2	$5\overline{)0}$	0×0	3×0	4×0	7×0	50
0×8	$7\overline{)0}$	0×7	0×0	$5\overline{)0}$	0×6	$9\overline{)0}$	0×3	9×0	$6\overline{)0}$	60
$5\overline{)0}$	$8\overline{)0}$	$6\overline{)0}$	0×0	0×2	$4\overline{)0}$	$9\overline{)0}$	4×0	$7\overline{)0}$	$1\overline{)0}$	70
0×7	0×0	8×0	$7\overline{)0}$	$6\overline{)0}$	0×1	$5\overline{)0}$	$3\overline{)0}$	$6\overline{)0}$	$6\overline{)0}$	80
$6\overline{)0}$	4×0	$6\overline{)0}$	3×0	0×6	8×0	$4\overline{)0}$	6×0	0×5	0×8	90
0×9	$6\overline{)0}$	$9\overline{)0}$	$1\overline{)0}$	$4\overline{)0}$	0×5	5×0	0×8	2×0	$8\overline{)0}$	100

Appendix C

Measure of Application

Chapter 2

Application: Multiplication and Division

$\begin{array}{r} 533 \\ \times\ 20 \\ \hline \end{array}$	$\begin{array}{r} 211 \\ \times\ 55 \\ \hline \end{array}$	$\begin{array}{r} 21 \\ \times\ 36 \\ \hline \end{array}$	$\begin{array}{r} 233 \\ \times\ 11 \\ \hline \end{array}$
$602 \div 6$	$424 \div 2$	$301 \div 3$	$660 \div 3$
$\begin{array}{r} 20 \\ \times\ 21 \\ \hline \end{array}$	$\begin{array}{r} 23 \\ \times\ 34 \\ \hline \end{array}$	$\begin{array}{r} 452 \\ \times\ 30 \\ \hline \end{array}$	$\begin{array}{r} 126 \\ \times\ 22 \\ \hline \end{array}$
$806 \div 4$	$807 \div 4$	$608 \div 5$	$505 \div 5$

Application: Multiplication and Division

$\begin{array}{r} 27 \\ \underline{\times\ 12} \end{array}$	$\begin{array}{r} 360 \\ \underline{\times\ 31} \end{array}$	$\begin{array}{r} 34 \\ \underline{\times\ 74} \end{array}$	$\begin{array}{r} 220 \\ \underline{\times\ 32} \end{array}$
$14.16 \div 6$	$16.59 \div 3$	$2.46 \div 2$	$4.26 \div 3$

$(4 \times 4) \times 2 =$ $(2 \times 8) \times 2 =$

$(5 \times 2) \div 5 =$ $(2 \times 9) \div 3$

Application: Multiplication and Division

$(2 \times 6) \div 3 =$ $(3 \times 8) \div 6 =$

$(5 \times 3) \times 4 =$ $(4 \times 7) \times 4 =$

$333 \div 3$ $242 \div 2$ $842 \div 4$ $601 \div 3$

$\begin{array}{r} 230 \\ \underline{\times\ 52} \end{array}$ $\begin{array}{r} 444 \\ \underline{\times\ 31} \end{array}$ $\begin{array}{r} 20 \\ \underline{\times 20} \end{array}$ $\begin{array}{r} 11 \\ \underline{\times 61} \end{array}$

Appendix D

Social Validity Questionnaire

Chapter 2

Student participant:______________

Date:__________________________

SECTION A	Yes	No	A little	A lot
1. Did you like doing your maths as fast as you could with the timer?				
2. Did you like reaching your goals?				
3. Did you find it hard to write your math facts quickly with the timer?				
4. Did you find it hard to reach your goals?				
5. Do you feel like learned your math facts well?				
6. Do you feel like you learned important things?				
7. Do you find it easier to do your maths in class?				
8. Do you think you are quicker at your maths now?				
9. Do you find it easier to learn new things in math class now?				
10. Do you find your maths homework easier to do?				
11. Are you able to do you maths homework quicker?				
12. Did you get frustrated when you didn't reach your goal?				
13. Did reaching your goals make you feel more confident / happy?				
14. Do you think you pay more attention to your maths written work now?				
15. Do you remember your math facts better?				

SECTION B	
16. What was your favourite part of learning your math facts fluently?	
17. What was your least favourite part of learning your math facts fluently?	
18. What was the most difficult part about learning your math facts fluently?	
19. What was the easiest part of learning your math facts fluently?	
20. How has it helped you?	
21. Is there anything that would make learning math facts fluently better / more fun / enjoyable?	
22. Would you like to learn more math facts fluently?	
23. Is there anything else you would like to tell me about your experience learning math facts fluently?	

Appendix E

Sample participant data collection sheet used in Chapter 3

Math Fact Fluency Student name:									
Slice in curriculum	**Goal**	**Timings**							**Goal met? Ask for your raffle ticket!**
New Facts 1 (3rd number)	60-50	**Date**	**1**	**2**	**3**	**4**	**5**	**6**	
New Facts 1 (Fact Sheet)	60-50	**Date**	**1**	**2**	**3**	**4**	**5**	**6**	
New Facts 2 (3rd number)	60-50	**Date**	**1**	**2**	**3**	**4**	**5**	**6**	

Appendix F

Samples of Morningside Math Facts: Addition and Subtraction

Chapter 3

Name ____________

Morningside Math Facts Fluency

Add-Subtract

2 5 7, 2 6 8

Box Sheet 4

2 5 7
2+5=7 5+2=7 7-5=2 7-2=5

2 6 8
2+6=8 6+2=8 8-2=6 8-6=2

2 6 8
2+6=8 6+2=8 8-6=2 8-2=6

2 5 7
2+5=7 5+2=7 7-5=2 7-2=5

Goal 4 - 6 seconds			
	Date	Family	Time
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Goal 4 - 6 seconds			
	Date	Family	Time
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Teacher Verified? Yes No

37

Name ___________

Morningside Math Facts Fluency

Add-Subtract

2 5 7, 2 6 8

Missing Number 4

___ 2 7	___ 2 8	2 ___ 7	___ 5 7
2 ___ 8	2 6 ___	5 2 ___	5 ___ 7
2 ___ 7	2 ___ 8	6 ___ 8	2 5 ___
___ 5 7	2 5 ___	___ 6 8	2 ___ 8
___ 2 7	5 2 ___	___ 6 8	___ 2 8
___ 2 8	5 2 ___	___ 2 7	___ 2 7
5 2 ___	5 2 ___	___ 5 7	___ 6 8
6 ___ 8	2 5 ___	2 ___ 7	5 2 ___
___ 5 7	___ 2 8	___ 2 7	6 ___ 8
___ 2 7	2 ___ 7	___ 6 8	5 ___ 7
___ 2 8	6 2 ___	5 ___ 7	2 5 ___
2 6 ___	6 2 ___	6 ___ 8	5 2 ___
2 ___ 8	___ 6 8	2 6 ___	2 ___ 8
6 2 ___	5 2 ___	2 ___ 7	2 ___ 8
___ 2 8	6 2 ___	5 ___ 7	5 2 ___
___ 6 8	2 ___ 8	___ 5 7	2 ___ 7
6 2 ___	5 2 ___	2 5 ___	5 ___ 7
6 2 ___	___ 2 8	5 2 ___	2 5 ___
2 ___ 8	2 5 ___	2 6 ___	6 2 ___
2 5 ___	2 ___ 8	___ 2 7	___ 6 8
___ 6 8	___ 2 8	___ 2 8	6 ___ 8
5 ___ 7	___ 2 8	5 2 ___	2 5 ___
___ 2 7	6 ___ 8	5 2 ___	6 ___ 8
6 2 ___	6 ___ 8	6 2 ___	___ 5 7
2 ___ 8	___ 2 8	2 ___ 8	6 2 ___
25	*25*	*25*	*25*

Version 2

Name ____________

Morningside Math Facts Fluency

Add-Subtract

2 5 7, 2 6 8

New Facts 4

7 -5	7 -2	5 +2	2 +6	8 -2	8 -6	6 +2	2 +5	2 +6	2 +5
7 -2	5 +2	7 -5	8 -2	6 +2	8 -6	6 +2	8 -2	2 +5	7 -2
7 -5	2 +6	8 -6	5 +2	7 -5	8 -6	8 -2	2 +6	6 +2	2 +5
5 +2	7 -2	2 +5	5 +2	7 -2	2 +6	6 +2	8 -2	8 -6	7 -5
7 -5	6 +2	8 -2	7 -2	5 +2	2 +6	2 +5	8 -6	8 -6	5 +2
2 +5	6 +2	2 +6	7 -5	8 -2	7 -2	8 -6	8 -2	6 +2	7 -2
2 +5	5 +2	7 -5	2 +6	7 -2	8 -6	2 +5	8 -2	7 -5	6 +2
2 +6	5 +2	6 +2	2 +6	8 -2	7 -2	2 +5	8 -6	7 -5	5 +2
7 -2	8 -2	5 +2	2 +6	2 +5	7 -5	6 +2	8 -6	7 -2	6 +2
2 +6	7 -5	2 +5	8 -6	8 -2	5 +2	5 +2	7 -2	8 -2	2 +6

Version 1

40

Appendix G

Samples of Morningside Phonics Fluency: Basic Elements

Chapter 3

Sample of "slice 1" from Morningside Phonics Fluency: Basic Elements

CV **BASIC ELEMENTS** **Slice 1**

fe	bo	le	ve	ni	gu	je	mu	pe	ha	10
di	sa	bi	ko	wa	ya	jo	si	ru	yi	20
ga	ba	vi	wi	du	po	za	co	te	ye	30
ne	cu	fo	mi	lu	zi	ku	se	ta	ha	40
lu	ve	ha	wi	ku	gu	le	bi	ne	zi	50
se	ni	si	vi	mi	yi	jo	ba	ta	ko	60
cu	fo	te	co	bo	ga	ru	sa	ye	du	70
pe	ha	wa	ya	fe	mu	po	za	di	je	80
wa	co	za	le	ba	mi	jo	yi	fo	ha	90
bo	ve	du	te	wi	cu	ga	ko	mu	po	100

Aim: 100 - 80 Corrects per Minute **Version 1 of 4**

Sample of "slice 3" from Morningside Phonics Fluency: Basic Elements

VCe **BASIC ELEMENTS** **Slice 3**

ope	oke	eze	ive	ose	ole	ife	ome	obe	ove	10
uge	oke	eke	ete	ole	ute	ave	ade	ive	afe	20
ame	ote	ake	uke	ipe	aze	ite	ede	ile	ase	30
ose	ide	obe	ele	ome	ife	ope	ibe	ove	eze	40
eme	ime	ene	ane	ise	afe	ipe	ole	uge	ane	50
aze	ove	ave	ide	oke	ile	ele	uke	ake	ope	60
ive	eme	eke	ite	ome	ene	ade	obe	ede	ibe	70
ete	ute	ase	ose	ame	ime	eze	ote	ise	ife	80
ete	ave	ise	ame	eze	ute	ibe	ide	ole	ome	90
ove	ake	ope	ose	ive	afe	ipe	ede	obe	eke	100

Aim: 100 - 80 Corrects per Minute **Version 3 of 4**

Appendix H

Sample Measure of Application with Mathematics

Morningside Whole Number Computation: Addition and Subtraction

Chapter 3

Morningside Math Fluency: Computation with Whole Numbers

Addition

Version: **1**

Facts: **1 – 4**

30 11 + 32	1,425 2,010 + 1,211	10 20 + 10	20 22 + 14	102 200 + 224	13/13
240 101 + 221	23 121 + 322	1,302 2,110 + 3,043	144 112 + 110	1,122 110 + 3,012	17/30
401 11 + 143	302 12 + 30	44 12 + 10	10 11 + 22	1,001 2,120 + 421	14/44
2,022 220 + 2,413	23 10 + 33	2,323 2,200 + 1,002	4,122 212 + 2,301	11 22 + 20	16/60
220 101 + 224	212 200 + 203	1,120 12 + 4,402	13 20 + 12	230 121 + 111	15/75

Morningside Math Fluency:
Computation with Whole Numbers
Subtraction

Version: **1** Facts: **1 – 4**

44,436 – 2,001	352 – 222	7,211 – 2,211	6,250 – 2,000	3,135 – 2,100	20/20
635 – 221	314 – 12	1,621 – 1,210	41,165 – 20,010	566 – 222	17/37
112 – 102	15,266 – 12,211	560 – 220	3,352 – 2,121	4,324 – 11	17/54
264 – 211	53,307 – 20,102	5,766 – 2,222	121 – 111	1,725 – 212	17/71
64,051 – 22,000	12,553 – 12,002	2,674 – 221	2,315 – 1	43,552 – 10,201	21/92

Appendix I

Sample measure of application with reading used in Chapter 3

DIBELS; Oral Reading Fluency (Good & Kaminski, 2002)

Ice Cream

When it is too hot outside, cold ice cream cools me off. I like strawberry the best, but rocky road is good, too. My brother likes bubble gum and vanilla.

The ice cream man comes down our street in the summer. When he gets close he rings his bell. All the kids hear the bell. They get some money and go outside and wait. They sit on the sidewalk until he comes. All of the kids want to buy some cold ice cream to eat.

The ice cream man has drumsticks, ice cream bars and bonbons. His ice cream tastes good. I like bonbons best.

My mother makes the very best ice cream of all. She uses our old ice cream freezer. She puts milk, sugar and eggs inside. She puts lots of ice inside, too.

I get to turn the handle. My hand gets cold and it takes a long time. My arm gets very tired turning the handle. Finally the ice cream is ready to eat. My mom lets me lick the ice cream paddle. I think the very first taste is the best.

Yum! That tastes great!

Appendix J

Chart used with participants in Chapter 3 and with participants in Chapter 4

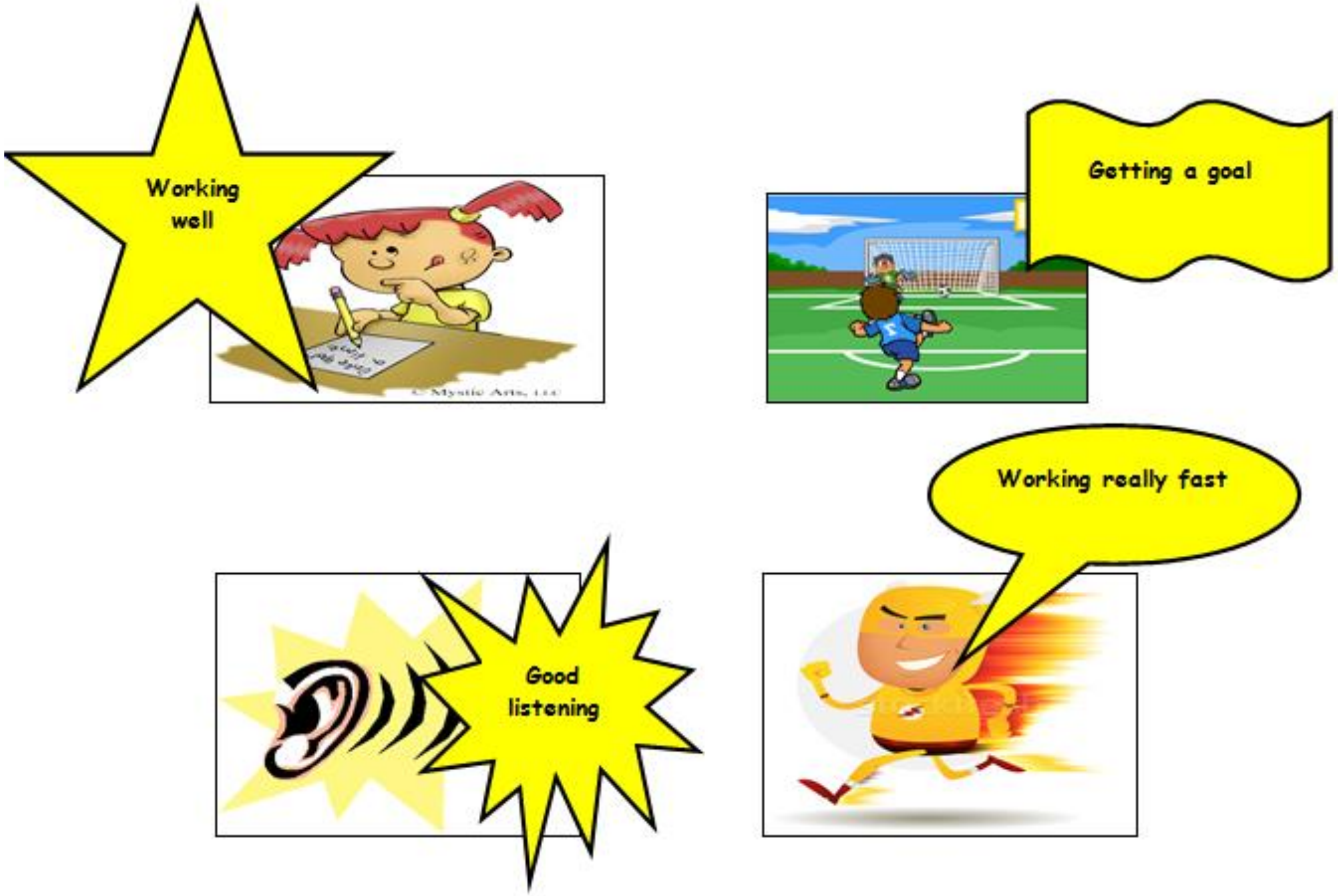
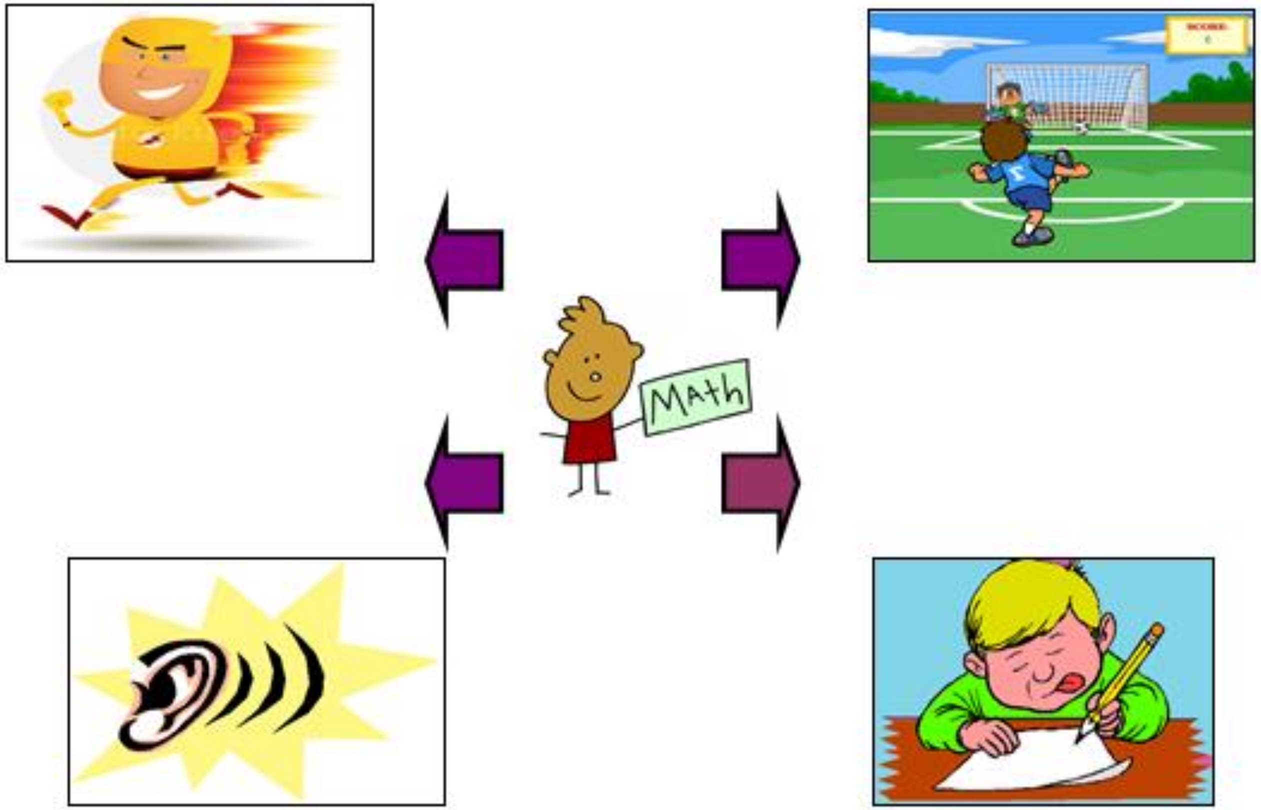
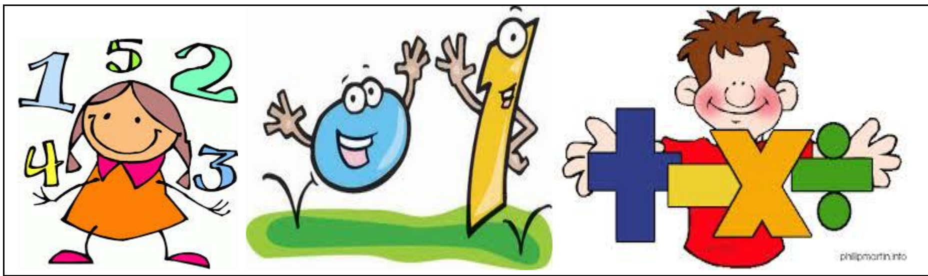


Chart used with participants in grades 4-6 in Chapter 4

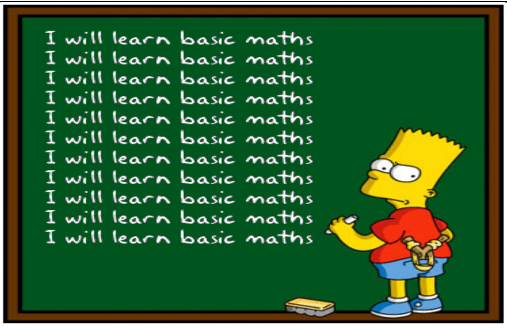


Appendix K

Social validity questionnaires used with participants 1-3 in Chapter 4

	Yes	No
1. It's important to learn your maths well		
2. I liked practicing my maths		
3. I learned my maths well		
4. I liked trying to get my goal		
5. I can add and take away faster now		
6. I liked working really fast and trying to beat the timer		
7. I can do my maths faster in class now		
8. Getting my goals made me feel good		
9. It's important to know your adding and taking away off by heart - this helps me do my maths better		

Social validity questionnaires used with participants 1-3 in Chapter 4

  	Yes	No
1. It's important to learn your maths well		
2. I enjoyed practicing my maths		
3. I learned my maths well		
4. I liked trying to get my goal		
5. I am faster with addition and subtraction now		
6. I enjoyed working really fast and trying to beat the timer		
7. Getting faster with addition and subtractions has helped me with my math in class		
8. Getting my goals made me happy / feel confident		
9. It's important to know addition and subtraction off by heart - it helps me do my maths better		