



Examining the Effectiveness of Metacognitive Strategies on Problem-Solving and Math Learning in Students with Dyslexia

Noorsaidah Binte Haja Mohideen^{1*}

1. Dyslexia Association of Singapore

Abstract

This study explores the metacognitive processes and emotional factors influencing the mathematical problem-solving experiences of secondary school students with dyslexia within the context of the Secondary 1 Normal Technical (Sec 1NT) Maths Curriculum. Utilising a purposive sampling method, two students who completed structured math intervention programs at the Dyslexia Association of Singapore (DAS) were selected. Through thematic analysis of their problem-solving approaches, guided by Schraw's (2001) metacognitive model and Stanton's (2012) framework for self-regulated learning, the study reveals critical insights into students' comprehension, strategy use and emotional regulation. Key findings include students' use of visual strategies, their familiarity with problem types and their difficulty adapting strategies in the face of challenges. Low self-confidence and limited emotional regulation were found to hinder their problem-solving effectiveness. The results underscore the need for targeted instructional practices that emphasise both metacognitive and emotional regulation strategies. Recommendations for integrating Polya's problem-solving framework and metacognitive assessments into existing curricula are proposed to improve students' mathematical outcomes. Limitations of the study and avenues for future research, including expanding sample sizes and exploring different mathematical contexts, are also discussed.

Keywords: Metacognition, mathematical problem-solving, dyslexia, POLYA framework, metacognitive strategies, secondary education, Dyslexia Association of Singapore, problem-solving skills

* Correspondence to:

Noorsaidah Binte Haja Mohideen, DAS Lead Educational Therapist, Dyslexia Association of Singapore.

Email: noorsaidah.haja@das.org.sg

INTRODUCTION

Metacognition, the ability to monitor and control one's cognitive processes, is essential for effective learning and problem-solving (Flavell, 1979). In mathematics, metacognition supports students by allowing them to plan, monitor and evaluate their problem-solving strategies, which is crucial for understanding complex mathematical concepts (Schoenfeld, 2016).

One prominent approach to fostering metacognitive skills in mathematics is the POLYA framework. This framework fosters metacognitive skills by structuring problem-solving into four steps: understanding, planning, executing and reviewing (Polya, 2004). This systematic approach encourages learners to reflect on their thinking, monitor progress, and adjust strategies, thereby enhancing confidence and effectiveness in mathematical problem-solving (Cornoldi et al., 2015).

Dyslexia, a specific learning disability impacting reading, phonological processing and working memory, introduces additional challenges in mathematics learning (Vellutino et al., 2004; American Psychiatric Association, 2013). Students with dyslexia often struggle with organising and reflecting on information, impeding their ability to apply metacognitive strategies effectively (Butterworth, Varma, & Laurillard, 2011; Schneider & Artelt, 2010). Moreover, difficulties with executive functioning, such as working memory and cognitive flexibility, exacerbate these challenges, making metacognitive training even more critical for these learners (Bull & Scerif, 2001; Cragg & Gilmore, 2014). Research shows that metacognitive training significantly enhances mathematical reasoning and problem-solving (Kramarski & Mevarech, 2003).

The Dyslexia Association of Singapore (DAS) incorporates the POLYA framework into its primary-level math program to address these needs by providing structured support for developing metacognitive skills (Cornoldi et al., 2015). However, older students without such training may struggle to self-regulate and solve problems independently, underscoring the importance of sustained metacognitive development in mathematics education (Mevarech & Amrany, 2008).

Research Gap

Current research on metacognition and mathematics problem-solving often lacks a detailed understanding of how dyslexic students specifically employ metacognitive strategies. While a wealth of studies exists regarding general metacognitive processes in educational settings (Schraw & Moshman, 1995; Kramarski & Mevarech, 2003), research focusing explicitly on dyslexic students' utilisation of these strategies in mathematics remains limited (Butterworth, Varma & Laurillard, 2011; Montague, 2008). This gap underscores the need to explore the specific metacognitive strategies that dyslexic

students use during mathematics problem-solving and the impact these strategies have on their problem-solving abilities (Schneider & Artelt, 2010; Cornoldi et al., 2015).

Personal Perspective

As a member of the DAS Maths Core Team, my dual role as therapist and curriculum developer has provided insight into how structured problem-solving approaches, such as the POLYA framework, support learners at the primary level. The explicit, step-by-step method helps students think through mathematical problems effectively. However, the secondary programme lacks such metacognitive scaffolding, revealing gaps in students' ability to process and apply strategies independently. Through my work with secondary learners, including those in Juvenile Homes, I observe similar difficulties affecting their confidence and accuracy. These experiences have motivated my interest in how secondary students with dyslexia use metacognitive strategies in mathematics. This research seeks to address this gap, aiming to inform instructional practices and enhance support for DAS students and other learners facing similar challenges (Tay, 2023).

Purpose of Research

This study aims to address the existing gap in literature by investigating the metacognitive processes that secondary school students with dyslexia engage in while solving mathematical problems. By understanding the specific metacognitive strategies these students employ, the research seeks to enhance current teaching methods. Furthermore, by analysing how these strategies influence their approaches to problem-solving, the study aims to provide valuable insights that can inform and improve instructional practices for dyslexic students in mathematics.

Research Questions

1. What strategies do dyslexic students use in mathematics learning?

This question aims to identify and categorise the specific strategies employed by dyslexic students during math problem-solving. Understanding these strategies is crucial for assessing their overall approach to learning mathematics.

2. Which of these strategies are metacognitive in nature?

This question seeks to determine which of the identified strategies involve metacognitive processes. Identifying metacognitive strategies will help in understanding how dyslexic students regulate their thinking and problem-solving processes, thereby addressing the gap in targeted teaching methods and support.

Study Objective

The objective of this study is to identify and analyse the metacognitive strategies used by secondary school students with dyslexia during mathematics problem-solving. By examining the specific strategies these students employ and determining which of these are metacognitive, the study aims to provide insights into how dyslexic students manage their cognitive processes in math. This understanding will inform the development of tailored instructional approaches to enhance mathematical problem-solving skills and improve educational outcomes for dyslexic learners.

LITERATURE REVIEW

Metacognitive Skills for Learning

Metacognition, encompassing the awareness and regulation of one's cognitive processes, is integral to effective learning and problem-solving. Defined by Flavell (1979) as "cognition about cognition," metacognition involves self-regulation, self-monitoring and strategic planning, which enable learners to manage and improve their cognitive processes. This concept comprises two main components: metacognitive knowledge and metacognitive regulation (Schraw & Moshman, 1995).

Metacognitive Knowledge refers to one's awareness of their cognitive processes, including understanding how different strategies work and when to use them. This type of knowledge can be divided into three categories: declarative knowledge (knowing about oneself and others as learners), procedural knowledge (knowing how to do things) and conditional knowledge (knowing when and why to use various strategies) (Schraw, 2001). For instance, a student who knows that summarising information can enhance comprehension demonstrates declarative knowledge, while knowing how to effectively summarise information reflects procedural knowledge.

Metacognitive Regulation, on the other hand, involves the control and adjustment of cognitive processes. It includes planning (setting goals and choosing strategies), monitoring (self-checking and awareness of one's comprehension and performance) and evaluating (assessing the outcomes and effectiveness of the chosen strategies) (Zimmerman, 2002). Effective metacognitive regulation allows learners to adapt their strategies in response to feedback and changing demands, thereby improving learning outcomes (Pintrich, 2002).

In addition to these broad categories, Stanton et al. (2021) provide a more granular framework, identifying six categories of metacognition:

1. Declarative Knowledge,
2. Procedural Knowledge,

3. Conditional Knowledge
4. Planning
5. Monitoring
6. Evaluating

The framework views metacognition as both an awareness of one's thinking processes and the ability to control and adjust those processes, with both components working together to enhance learning effectiveness.

Studies have consistently shown that metacognitive skills are crucial for academic success. For example, students who exhibit strong metacognitive abilities are better at organising their learning, using effective strategies and self-assessing their performance (Schraw & Moshman, 1995; Dunlosky et al., 2013). Additionally, research has demonstrated that teaching metacognitive strategies can lead to significant improvements in students' academic performance (Efklides, 2011). Techniques such as self-questioning, reflection and strategy use have been shown to enhance students' ability to manage their learning processes effectively (Schraw & Moshman, 1995; Perry et al., 2019). The six categories of metacognition, as outlined by Stanton et al. (2021), provide a comprehensive guide to these techniques, ensuring a holistic approach to fostering metacognitive development.

Dyslexia and Metacognition

Dyslexia, characterised by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities (Vellutino et al., 2004), presents unique challenges to metacognitive regulation. Dyslexic students often struggle with phonological processing and executive functions, which are vital for effective metacognitive control (Snowling, 2012). These challenges can impede their ability to engage in self-monitoring and strategic adjustment, crucial components of metacognitive regulation (Butterworth et al., 2011).

Research has indicated that dyslexic individuals frequently exhibit deficits in working memory and processing speed, which can affect their metacognitive abilities. For example, dyslexic students may have difficulty maintaining and manipulating information necessary for planning and monitoring their problem-solving strategies (Snowling et al., 2020; American Psychiatric Association, 2013). These cognitive limitations can hinder their ability to employ and regulate metacognitive strategies effectively, impacting their overall learning and academic performance.

Moreover, difficulties with executive functions, such as inhibition, cognitive flexibility and working memory, are commonly observed in dyslexic students (Bull & Scerif, 2001). These executive functions are closely linked to metacognitive skills, as they facilitate the planning, monitoring and evaluation of cognitive processes. The impaired executive

functions in dyslexic students can therefore limit their ability to use metacognitive strategies effectively (Butterworth et al., 2011).

Given these challenges, there is a growing need to explore how dyslexic students engage in metacognitive processes and to identify effective strategies for supporting their learning (Vellutino et al., 2004). Research focusing on dyslexic students' metacognitive strategies in specific learning contexts, such as mathematics, is particularly scarce and warrants further investigation.

Dyslexia, Metacognition and Mathematics Learning

Mathematics learning poses distinct challenges for dyslexic students, compounded by difficulties in metacognitive regulation. Dyslexic students often experience difficulties with number processing, working memory and executive functions, all of which are crucial for effective problem-solving in mathematics (Butterworth et al., 2011; Passolunghi & Siegel, 2004). These cognitive difficulties can hinder their ability to engage in metacognitive strategies and affect their mathematical problem-solving performance.

Research has shown that dyslexic students often struggle with spatial and numerical processing, which can impact their mathematical reasoning (Gersten et al., 2005). For instance, difficulties with spatial awareness and working memory can affect their ability to visualise mathematical problems and manipulate numerical information effectively (Bull & Scerif, 2001). Additionally, deficits in executive functions can hinder their ability to plan, monitor and evaluate their problem-solving processes, further complicating their mathematical learning (Cornoldi et al., 2015).

Although there is substantial evidence on general metacognitive processes and their role in learning, studies specifically focusing on dyslexic students' use of metacognitive strategies in mathematics are limited (Desoete et al., 2001). Research has primarily concentrated on general metacognitive skills rather than exploring how these skills are applied in specific contexts such as mathematics (Kramarski & Mevarech, 2003). This gap highlights the need for more targeted research to understand how dyslexic students utilise metacognitive strategies during mathematical problem-solving and how these strategies influence their performance.

Recent studies have begun to address this gap by examining the effects of metacognitive training on mathematical problem-solving in dyslexic students. For example, research has shown that metacognitive instruction can enhance mathematical reasoning and problem-solving abilities in students with learning difficulties (Çiftçi & Çakıroğlu, 2019; Mevarech & Amrany, 2008). These studies suggest that targeted metacognitive interventions, incorporating elements such as planning, monitoring and evaluation can improve dyslexic students' ability to regulate their cognitive processes and enhance their mathematical performance.

POLYA Framework and Its Role in Developing Metacognition

The POLYA framework, as outlined in George Polya's seminal work *How to Solve It*, provides a structured approach to developing metacognitive skills in problem-solving (Polya, 2004). Polya's framework consists of four main steps: understanding the problem, devising a plan, carrying out the plan and reviewing the solution. This structured approach encourages students to engage in metacognitive activities such as planning, monitoring and evaluating their problem-solving processes.

- ◆ **Understanding the Problem** involves clarifying the problem, identifying relevant information and determining what needs to be solved. This step requires students to engage in self-monitoring and reflection to ensure they comprehend the problem correctly.
- ◆ **Devising a Plan** involves creating a strategy for solving the problem. This step requires students to use their metacognitive knowledge to select appropriate strategies and plan their approach.
- ◆ **Carrying out the Plan** involves implementing the chosen strategy and working towards a solution. During this phase, students must continuously monitor their progress and make adjustments as needed.
- ◆ **Reviewing the Solution** involves evaluating the effectiveness of the solution and reflecting on the problem-solving process. This step encourages students to assess their strategies and consider alternative approaches if necessary.

Polya's framework not only provides a structured approach to problem-solving but also fosters the development of metacognitive skills. By following these steps, students learn to reflect on their cognitive processes, adjust their strategies and enhance their overall problem-solving abilities (Schoenfeld, 2016). The inclusion of reflection as a distinct step aligns with Stanton et al.'s (2021) expanded framework, underscoring the importance of post-task evaluation and self-assessment to refine future strategies.

Research has shown that implementing Polya's framework can improve students' mathematical reasoning and problem-solving skills. For example, studies have demonstrated that teaching Polya's strategies can enhance students' ability to plan, monitor and evaluate their problem-solving processes, leading to improved mathematical performance (Kramarski & Mevarech, 2003). Additionally, Polya's framework has been shown to be effective in helping students with learning difficulties, such as dyslexia, develop better problem-solving skills by providing them with clear, structured strategies to manage their cognitive processes (Çiftçi & Çakıroğlu, 2019).

DAS Maths Programme

The DAS Maths Programme is a specialised intervention designed to support students with dyslexia and other learning differences who face challenges in mathematics. This programme addresses various difficulties students may encounter, including comprehending mathematical language, recalling mathematical facts, executing procedures accurately, understanding mathematical concepts and solving problems. To cater to the diverse needs of these learners, the DAS Maths Programme offers three distinct curriculums: The Essential Maths Curriculum (ESS), the Problem Sums for Upper Primary (PSUP) Curriculum and the Secondary 1 Normal Technical (Sec 1NT) Maths Curriculum.

Both the ESS and PSUP programmes incorporate the POLYA framework and the Try-Share-Learn-Apply approach, providing structured methodologies that enhance students' metacognitive and problem-solving skills. In contrast, the Sec 1NT Programme, while not explicitly using any established framework, aims to bridge curriculum gaps and equip students with the necessary skills for successful progression in secondary mathematics.

- ◆ **Essential Maths Curriculum (ESS):**

This curriculum targets Primary 1 to 6 students and focuses on fundamental mathematical concepts. Students in the ESS Programme receive one hour of remediation per week, with lessons tailored to their individual needs and learning pace. The ESS Curriculum employs the Concrete-Representational-Abstract (C-R-A) approach, which helps students visualise mathematical concepts through tangible objects and visual representations before progressing to abstract equations. This method supports a gradual and comprehensive understanding of mathematical principles. Additionally, students are introduced to systematic problem-solving techniques using Polya's Four-Step Process (1945), which aids in comprehending and organising information in language-based problems, therefore promoting structured and logical problem-solving skills.

- ◆ **Problem Sums for Upper Primary (PSUP):**

Aimed at Primary 5 and Primary 6 students, the PSUP Curriculum addresses the cognitive and metacognitive challenges associated with solving word problems in the Standard Mathematics syllabus. This programme incorporates the Try-Share-Learn-Apply approach, where students independently tackle a word problem, share their thought processes with the class and then learn and apply specific heuristic strategies introduced by their therapist. This method enhances students' thinking and communication skills while allowing them to refine their problem-solving techniques.

◆ **Secondary 1 Normal Technical (Sec 1NT):**

Designed for students following the Secondary 1 Normal Technical maths syllabus, the Sec 1NT Programme provides curriculum-based support to bridge the gap between primary and secondary school mathematics. The curriculum is structured into ten-hour instructional blocks each term, focusing on Normal Technical mathematical concepts and application questions relevant to real-world scenarios. This targeted approach aims to boost students' confidence and proficiency in secondary school mathematics, ensuring they are well-prepared and engaged with the subject matter.

Each of these programmes employs dyslexia-friendly teaching methodologies and systematic approaches to address the specific needs of the students, ensuring that they receive tailored support to enhance their mathematical understanding and problem-solving abilities.

METHODOLOGY

Study Design and Sample

This study adopts a qualitative research design to explore the metacognitive processes of students with dyslexia during mathematical problem-solving. Specifically, the study focuses on two participants diagnosed with dyslexia, who are enrolled in the same math intervention programme. The choice of a small sample size is deliberate, aiming to facilitate an in-depth, exploratory investigation into the participants' metacognitive strategies (Desoete, Roeyers & Buysse, 2001).

Sampling, Participants and Selection Criteria

A purposive sampling technique was employed to select participants who could provide comprehensive and detailed insights into the research topic and effectively address the research questions (Suri, 2011; Forman et al., 2008). This approach was deemed suitable given the need for participants to possess specific experience related to the implementation and effectiveness of metacognitive strategies in math problem-solving for students with dyslexia.

Two participants were chosen through purposive sampling, given their relevant experience and completion of the math intervention programs. This selection was based on the criterion that both participants had previously engaged with DAS's math programmes and had demonstrated a range of metacognitive strategies during their prior educational experiences. The use of a small, focused sample size allowed for an in-depth exploration of their metacognitive strategies in solving mathematical problems, aligning with the study's aim to understand specific challenges and strategies in this context (Creswell, 2013).

The focus of this study was on secondary school students with dyslexia who had completed a structured math intervention programme at the Dyslexia Association of Singapore (DAS). These students were selected based on their participation in the Primary School Essential Math Programme followed by a year-long Secondary One programme at DAS. The intent was to explore their metacognitive processes during math problem-solving tasks, utilising their direct experience with targeted interventions.

The selection criteria for participants required that they:

1. Be secondary school students diagnosed with dyslexia.
2. Have completed both the Primary School Essential Math Program and the Secondary One program at DAS.
3. Be able to articulate their problem-solving processes during the task, providing insights into their metacognitive strategies and challenges.

The participants are purposefully selected to ensure homogeneity. Both students have been diagnosed with dyslexia and have previously engaged in the same math intervention program. This selection criterion allows for a focused examination of how metacognitive processes manifest in students with similar educational backgrounds and cognitive profiles (Vellutino et al., 2004). The use of a small sample size permits a thorough and nuanced analysis of individual experiences and strategies, which might be obscured in larger studies (Polya, 2004).

By examining the responses and problem-solving techniques of these two carefully selected students, the study aimed to uncover nuanced insights into the application of metacognitive strategies and identify areas for improvement in current instructional practices. This focused approach provided valuable preliminary data on the specific metacognitive processes employed by students with dyslexia during math problem-solving, facilitating the development of more tailored educational interventions.

Metacognitive Framework for the Study

This study employed Stanton et al.'s (2021) six-category metacognitive framework, integrated with the foundational model proposed by Schraw and Moshman (1995), to explore how dyslexic students engage in metacognitive strategies during mathematical problem-solving. The combination of these frameworks provided a comprehensive structure for understanding the cognitive and metacognitive processes dyslexic students used when solving math problems.

Table 1. Student Profiles

	Student A	Student B
Gender	Female	Male
Age	15	14
School Level	Secondary Two (Normal Technical)	Secondary Two (Normal Technical)
Background Information	<ul style="list-style-type: none"> ◆ Raised in a bilingual speaking environment - Main language spoken is English ◆ No known history of learning difficulties in family ◆ Repeated pre-school for one more year ◆ No significant behavioural or attention issues reported or observed 	<ul style="list-style-type: none"> ◆ Raised in a bilingual speaking environment - Main language spoken is English ◆ No reports of a history of learning difficulties in family ◆ No significant behavioural or attention issues reported or observed ◆
Diagnosis	<ul style="list-style-type: none"> ◆ Dyslexia ◆ Mild to moderate hearing loss in left ear ◆ (assessed to be stable since 2016 and reported that level of hearing was adequate for schooling and learning and following instructions) 	<ul style="list-style-type: none"> ◆ Dyslexia
Intervention Educational Support	<ul style="list-style-type: none"> ◆ Received language and literacy support in pre-school at DAS (2 years) ◆ Received additional academic help through external and school support since primary school. ◆ Attending the Main Literacy programme since the age of 10 years (2019) till current at DAS. ◆ Received Speech and Language support since 2019 till 2021 at DAS. ◆ Attended the Math intervention programme from 2019 till 2021. 	<ul style="list-style-type: none"> ◆ Received academic school support since primary school. ◆ Attending the Main Literacy programme since Primary 1 till current at DAS. ◆ Attended the Math intervention programme from 2019 till 2021.

Table 1. (Cont') Student Profiles

	Student A	Student B
Psychological Assessment	<ul style="list-style-type: none"> ◆ Last assessment done in 2019: ◆ Adequate processing speed and visual working memory. ◆ Adequate rote verbal memory, but weak in manipulating verbal information mentally. ◆ Showed weak quantitative reasoning ability along with very poor abstract reasoning ability and extremely weak visual-spatial ability. ◆ Displayed weak verbal ability, oral language skills and word retrieval fluency. ◆ Observed to be very weak in phonological awareness and poor phonological decoding, word reading, reading comprehension and passage reading accuracy. ◆ Struggled in word spelling, sentence, and composition writing as well. ◆ Displayed weak understanding of basic mathematical concepts and ability to use concepts and operations to solve problems. ◆ Obtained average scores on the written and mental computation tasks but rely on using fingers when doing calculations and struggled with sums on division. 	<ul style="list-style-type: none"> ◆ Last assessment done in 2020: ◆ Adequate single-word reading and reading comprehension skills, as well as passage reading speed. ◆ Weak passage reading accuracy and very weak phonological decoding skills. ◆ Struggled with vowels and suffixes, and relied on a whole-word reading approach. ◆ Reading accuracy deteriorated when task demands increased (i.e. from single words to passages). ◆ Displayed weak single-word spelling skills and copying fluency, as well as weaknesses in composition writing fluency, despite having adequate sentence writing fluency. ◆ Observed spelling errors, poor sentence structures, inconsistent usage of grammar and writing conventions, as well as poor organisation. ◆ Displayed weak mathematical fluency, particularly when solving addition and multiplication questions, gaps in knowledge of arithmetic facts.

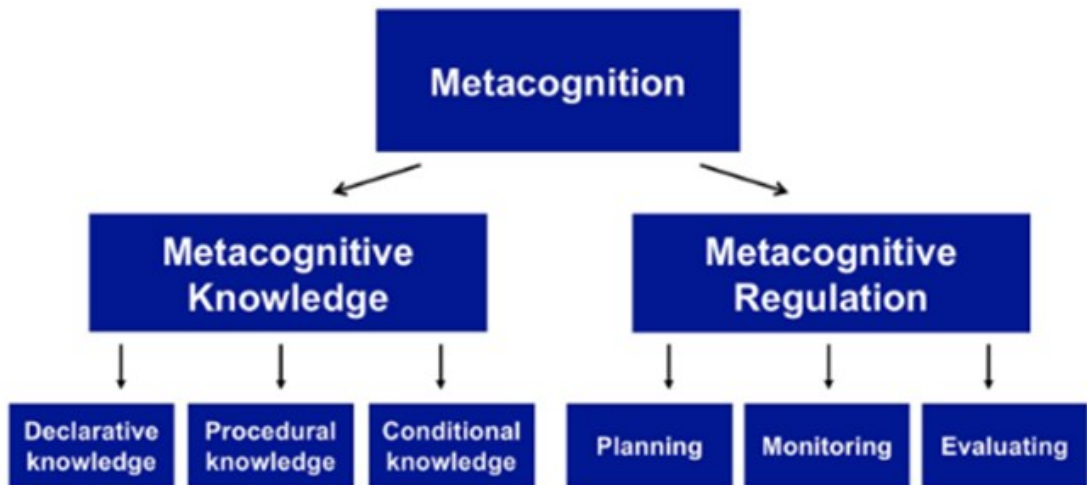


Figure 1. Metacognitive Processes in Learning (Stanton et al. 2021)

Why This Framework Was Chosen

The Stanton et al., (2021) framework (refer to diagram below) was selected for its detailed categorisation of metacognition, expanding beyond the conventional understanding to include specific categories relevant to structured learning environments such as mathematics. These categories: metacognitive knowledge and metacognitive regulation (planning, monitoring and evaluation), offered a robust structure to examine not only how students planned and executed their strategies but also how they reflected on their performance. This fine-grained analysis was essential for understanding how dyslexic students managed their cognitive processes, particularly in complex subjects like math.

In particular, Polya's (2004) four-step problem-solving model, which emphasises understanding the problem, devising a plan, carrying out the plan and looking back, aligned well with the planning, monitoring and evaluating stages in Stanton's framework. This connection made the Stanton model a strong fit for studying problem-solving in mathematics.

The integration of Schraw and Moshman's (1995) model, which distinguishes between metacognitive knowledge and metacognitive regulation, complemented Stanton et al.'s categories by emphasising how students' awareness of their cognitive processes influenced their learning. Schraw and Moshman's declarative, procedural and conditional knowledge subtypes helped explore how dyslexic students decided when and how to apply specific strategies during problem-solving (Schraw & Moshman, 1995). This combination enabled the study to provide a detailed view of both strategy selection and self-regulation.

Integration of Other Relevant Literature

Studies on metacognition in math problem-solving showed that students with learning difficulties, including dyslexia, often faced challenges with executive function, particularly working memory and self-monitoring, which were crucial for success in mathematical tasks (Butterworth, Varma, & Laurillard, 2011; Cragg & Gilmore, 2014). This underscored the importance of focusing on metacognitive regulation, a key element of both Stanton et al.'s and Schraw and Moshman's frameworks, as it helped students monitor their progress and adjust strategies accordingly.

Research by Desoete et al. (2001) and Kramarski and Mevarech (2003) further supported the use of metacognitive strategies to enhance mathematical reasoning and problem-solving abilities. Dyslexic students, in particular, benefited from explicit instruction in self-regulation and reflective thinking, both of which were essential for improving their mathematical outcomes (Desoete, Roeyers, & Buysse, 2001; Kramarski & Mevarech, 2003).

Application of the Framework in This Study

The study used this combined framework to explore specific metacognitive strategies dyslexic students employed during mathematics problem-solving. By categorising and analysing strategies based on planning, monitoring and evaluating, the research provided insights into how dyslexic students regulated their cognitive processes. For example:

- 1. Planning:**
This involved investigating how students prepared to tackle a mathematical problem, drawing on procedural knowledge as outlined by Schraw and Moshman (1995). This phase also aligned with Polya's (2004) approach of devising a plan.
- 2. Monitoring:**
The study explored how students tracked their progress during problem-solving, which tied into metacognitive regulation and self-monitoring, essential components in both the Stanton and Schraw frameworks (Schraw & Moshman, 1995; Stanton et al., 2021).
- 3. Evaluating:**
This phase examined how students assessed their problem-solving performance and learned from their experiences, connecting with conditional knowledge and the evaluating category in Stanton's model. This phase was crucial for understanding how dyslexic students improved their strategies over time (Stanton et al., 2021; Schraw & Moshman, 1995).

The Stanton et al. (2021) framework guided the research questions, particularly the second one: Which of these strategies are metacognitive in nature? By identifying specific behaviours related to monitoring and evaluating, the research pinpointed the metacognitive strategies that dyslexic students used and explored how these behaviours influenced their problem-solving success.

Implications for Teaching

Building on prior work by Schoenfeld (2016) on mathematical thinking, the study aimed to inform instructional practices that explicitly taught metacognitive strategies to dyslexic students. Incorporating both Stanton et al. and Schraw and Moshman's (1995) models ensured that the research captured a comprehensive view of how dyslexic students approached problem-solving. This insight contributed to more effective teaching methods that fostered self-regulated learning, a critical component in mathematics education for dyslexic learners (Zimmerman & Schunk, 2001; Zimmerman, 2002).

Data Collection

The primary data collection methods involved think-aloud protocols and direct observation. Think-aloud protocols required participants to verbalise their thought processes as they engaged in solving mathematical problems. This approach provided real-time insights into the metacognitive strategies employed and the challenges faced during problem-solving (Schraw & Moshman, 1995). Direct observation supplemented this data, focusing on participants' problem-solving techniques, verbalisations and interactions with the math problems (Cornoldi et al., 2015).

The integration of think-aloud protocols with observational data allowed for a comprehensive understanding of participants' metacognitive processes. This dual approach captured both the verbalized and non-verbal aspects of problem-solving, providing a rich dataset for analysis (Kramarski & Mevarech, 2003).

For this study, a mathematical question (Appendix) from the topic of 'Direct and Indirect Proportion' was selected. The question was drawn from Tay (2023), Secondary 2 (Normal Technical) Maths Topical Revision 4th Edition, published by Education Publishing House Pte Ltd. Specifically, Question 6 from the End of Year Revision Paper was used to assess students' problem-solving processes. The selection of this topic was strategic, as proportional reasoning plays a fundamental role in various aspects of mathematics, including fractions, ratios, algebra and real-world contexts such as measurement, rates and probability (Modestou & Gagatsis, 2010).

By using this cognitively demanding question, the study aimed to explore the metacognitive strengths and weaknesses of the participants, who had already been taught this topic in school. Proportional reasoning, a key skill in mathematics, is closely

tied to abstract and logical thinking and the ability to recognize, represent and reason about multiplicative relationships between quantities is crucial for students' mathematical development. The selected question, therefore, served as a suitable vehicle for evaluating how students with learning differences, particularly those with dyslexia, applied metacognitive strategies during problem-solving tasks.

A structured interview guide was developed based on three metacognitive strategies, aligned with the POLYA four-step problem-solving framework. The questions were designed to elicit the participants' thought processes during problem-solving and were used in conjunction with the mathematical task to evaluate their metacognitive awareness and strategy use. By using this structured approach, the research aimed to collect rich, detailed data on how students with dyslexia approach mathematical problem-solving, providing a deeper understanding of their strengths and the challenges they faced.

Ethical Considerations

The study adhered to ethical guidelines as outlined by Creswell (2009) to ensure the integrity and ethical conduct of the research. The following ethical considerations were implemented:

1. **Approval and Consent:**
Prior approval was obtained from the Dyslexia Association of Singapore (DAS) Research Committee to conduct the study involving interviews at a DAS centre (Creswell, 2009). Participants provided informed consent, ensuring that they fully understood and agreed to their involvement in the research, as recommended by Gregory (2003). This process involved clear communication regarding the study's objectives, procedures and any potential risks or benefits.
2. **Confidentiality and Anonymity:**
Measures were put in place to maintain the confidentiality and anonymity of participants in accordance with the guidelines of the British Educational Research Association (2018). Participants were assigned pseudonyms to protect their identities in all reports and publications. Additionally, all collected materials were encrypted and securely stored to prevent unauthorized access.
3. **Data Retention and Disposal:**
Data were retained securely until the completion and submission of the project. Following the conclusion of the research, data were responsibly disposed of to ensure that participant information is no longer accessible or usable (British Educational Research Association, 2018).

By adhering to these ethical practices, the study aimed to uphold the highest standards of research integrity while respecting and protecting the rights and confidentiality of all participants involved.

Data Analysis

The data analysis for this study utilised Braun and Clarke's (2006) six-stage thematic analysis model, which was particularly well-suited for exploring qualitative data and identifying key themes related to the research inquiry. This method aligned with the objectives of this study, which investigated how students with dyslexia employed metacognitive strategies during math problem-solving. The thematic analysis provided a structured approach to uncovering patterns within the data and understanding the nuances of participants' experiences and strategies.

The six stages of thematic analysis included:

1. **Familiarisation with the Data:**

The researcher began by immersing herself in the data through active and repeated reading. This process involved transcribing audio recordings and listening to them to gain a thorough understanding of the data and identify preliminary patterns (Lapadat and Lindsay, 1999). This stage was crucial for developing a deep comprehension of the content and the context of participants' problem-solving processes.

2. **Generating Initial Codes:**

During this phase, initial codes were created to capture significant aspects of the data. This involved manually coding the text by noting relevant patterns and using tools like the 'comment' function in Microsoft Word. The goal was to highlight emerging themes related to metacognitive strategies and challenges faced by the participants (Braun and Clarke, 2006).

3. **Searching for Themes:**

Codes were then organised into potential themes. The researcher used an Excel sheet to map out these codes and constructed a thematic map, as suggested by Braun and Wilkinson (2003). This visual representation helped to categorise codes into broader themes and identify connections between them, with a focus on how students with dyslexia approached and solved math problems.

4. **Reviewing Themes:**

The identified themes were reviewed to assess their relevance and coherence. This involved evaluating the themes against the data to ensure they accurately represented the findings. Weak or redundant themes were either refined or discarded. This phase also included sharing preliminary findings with

participants to validate the themes and ensure they reflected the participants' experiences (Birt et al., 2016).

5. **Defining and Naming Themes:**

Each theme was analysed in detail to understand its core idea and the data it represented. This stage involved defining and naming themes to clearly articulate how each theme related to the research questions about metacognitive strategies and challenges in math problem-solving.

6. **Writing Up:**

The final stage involved presenting the analysed themes and data in a coherent, logical manner. The themes were woven into the narrative to address the research questions, providing a structured and detailed account of the findings. Throughout this process, reflexivity was maintained to address researcher bias. Personal memos were kept to document thoughts and ethical considerations, ensuring the validity and credibility of the study (Hammarberg et al., 2016; Johnson, 1997).

This rigorous approach to thematic analysis facilitated a comprehensive understanding of how students with dyslexia utilised metacognitive strategies during math problem-solving, aligning with the study's aims and providing valuable insights into the challenges and strategies involved.

RESULTS AND DISCUSSION

The thematic analysis of student responses revealed critical insights into their cognitive and emotional processes during mathematical problem-solving. By applying Stanton's (2012) framework for self-regulated learning and Schraw's (2001) metacognitive model, the study deepened the understanding of the identified themes, which aligned with the research objectives aimed at exploring students' comprehension, strategy utilisation and the emotional factors affecting their problem-solving experiences.

Understanding and Explanation of the Problem

One salient theme was the students' ability to articulate the math question in their own words, demonstrating an understanding of the problem's requirements. This capability relates to Stanton's (2012) emphasis on **self-monitoring**, wherein learners assess their understanding and comprehension of tasks. By reformulating the problem, students engaged in a metacognitive strategy that aligns with Schraw's (2001) notion of **declarative knowledge**, which includes awareness of one's cognitive processes. This understanding was foundational for effective problem-solving and supported the objective of examining students' comprehension and strategy selection.

Familiarity with the Problem

Students expressed familiarity with the problem, indicating that prior exposure provided them with a framework for tackling the task. This reflected Stanton's (2012) concept of **self-regulation**, where students utilised prior experiences to inform their current strategies. Their recognition of having "seen this question before" suggests that structured instructional practices emphasising related problem types can significantly bolster student confidence, aligning with the objective of exploring the strategies employed during problem-solving (Vellutino et al., 2004).

Use of Visual Strategies

The use of tables by students to visualise the information highlighted a practical application of cognitive strategies, echoing Schraw's (2001) emphasis on **metacognitive regulation**, the ability to plan, monitor and evaluate one's approach to learning. This supports findings from Laski et al. (2015) regarding the effectiveness of visual aids in enhancing mathematical understanding. By organising their thoughts through visual representations, students clarified their reasoning processes, directly aligning with the research objective of examining the strategies utilized during problem-solving.

Inability to Adapt Strategies

A significant limitation observed was the students' difficulty in generating alternative strategies when faced with challenges. This rigidity spoke to Stanton's (2012) **self-reflection** phase, where learners should ideally evaluate the effectiveness of their chosen methods. The inability to adapt strategies underscored a gap in their **adaptive reasoning** skills (Schoenfeld, 2016). Although they identified a method, their lack of flexibility hindered their problem-solving effectiveness. Instructional interventions that cultivate flexible thinking and multiple methods of solution could be beneficial in developing this essential skill (Cornoldi et al., 2015).

Lack of Confidence

The analysis revealed a concerning theme of low self-efficacy among students, reflected in their uncertainty about the accuracy of their answers. Stanton (2012) put forward that self-efficacy is critical in the **self-regulation** process, as individuals who doubt their abilities are less likely to persevere through challenges. This finding was vital as it aligned with the research objective of understanding the emotional factors impacting problem-solving. Enhancing students' self-efficacy through positive reinforcement and constructive feedback may help mitigate anxiety and bolster confidence in problem-solving situations.

Emotional Regulation and Coping Strategies

Student reported using deep breathing as a coping mechanism when facing challenges, indicating an awareness of the emotional dimensions of problem-solving. This behaviour aligns with Gross's (2002) model of **emotional regulation** and connects to Stanton's (2012) framework, which emphasises the importance of managing emotional responses to achieve cognitive goals. Encouraging students to develop emotional regulation strategies could support their persistence and resilience in mathematical tasks, aligning with the objective of exploring the emotional factors involved in problem-solving.

Awareness of Errors

Finally, the recognition of inaccuracies in their calculations suggested a degree of **self-monitoring** and reflective practice (Schraw, 2001). This awareness, a key aspect of metacognitive regulation, enabled them to identify areas for improvement and aligns with Stanton's (2012) call for self-evaluation within the learning process. Fostering this reflective practice within the classroom environment could further enhance students' problem-solving skills, meeting the objective of promoting metacognitive awareness. In summary, the thematic analysis highlighted several critical factors influencing students' mathematical problem-solving experiences, viewed through the lenses of Stanton and Schraw's frameworks. The findings underscored the importance of understanding problem comprehension, strategy utilisation, emotional factors and self-regulation. By integrating these insights into instructional practices, educators can better support students in developing the cognitive and emotional competencies necessary for effective mathematical problem-solving. Future research could explore specific interventions aimed at enhancing metacognitive and emotional regulation strategies to further improve student outcomes in mathematics.

RECOMMENDATIONS

Understanding the stages at which learners are in their problem-solving processes is crucial, especially within the context of the Secondary 1 Normal Technical (Sec 1NT) Maths Curriculum. According to Schraw and Moshman's (1995) metacognitive framework, awareness of one's cognitive processes can significantly impact learning outcomes. By identifying where students struggle, educators can tailor instructional strategies to meet their specific needs.

To identify gaps in metacognitive skills effectively, implementing a checklist outlining these skills across the categories in the framework can serve as an informal assessment tool prior to introducing new topics. This approach aligns well with the principles set forth in the DAS Maths Programme, which aims to support students with dyslexia and other learning differences by addressing their unique challenges in mathematics.

Given that many topics in the Secondary 1 curriculum are abstract, a more structured use of Polya's problem-solving framework could be beneficial. Although Polya's Four-Step Process (1945) is not explicitly integrated into the secondary mathematics curriculum, its principles could enhance students' comprehension and organisational skills in tackling language-based mathematical problems. By encouraging students to visualise mathematical concepts and apply systematic problem-solving techniques, educators can help students feel more confident and capable in their mathematical abilities.

In summary, the findings from this study indicated a significant need for tailored instructional methods that consider students' metacognitive processes during problem-solving. By implementing the recommendations outlined above, educators can better prepare students for the challenges they face in the Secondary 1 Normal Technical Maths Curriculum, ultimately enhancing their mathematical proficiency and confidence.

LIMITATIONS AND FUTURE RESEARCH

This study presented several limitations that must be acknowledged. Firstly, the research was conducted with only two secondary school learners, which restricted the generalisability of the findings. The small sample size limits the ability to draw broader conclusions about the metacognitive processes and problem-solving strategies employed by a larger population of secondary school students (Creswell, 2014). Additionally, the analysis was based on the completion of a single math question, which may not fully capture the complexity of students' metacognitive awareness and problem-solving abilities across different mathematical contexts and types of questions.

Moreover, this study focused solely on the Secondary 1 Normal Technical (Sec 1NT) Maths Curriculum. Future research should consider expanding the sample size to include a more diverse group of learners across different educational settings and various mathematical topics. Investigating how students approach different types of math problems, such as word problems, numerical calculations, or abstract concepts, could provide a more comprehensive understanding of their metacognitive strategies (Schraw & Moshman, 1995).

Another potential research gap lies in the integration of Polya's problem-solving framework within the secondary mathematics curriculum. Future studies could explore how explicit instruction in Polya's method impacts students' confidence and problem-solving efficacy. Additionally, research could investigate the long-term effects of metacognitive training on students' academic performance in mathematics, as well as how such training could be systematically implemented within existing curriculum (Zimmerman, 2002).

In summary, while this study contributed valuable insights into the metacognitive processes of secondary school learners, it also highlights the need for further exploration

and understanding in this area. Addressing these limitations and research gaps will enhance educational practices and support for students facing challenges in mathematics.

CONCLUSION

This research aimed to explore the metacognitive processes of secondary school learners engaged in problem-solving within the context of the Secondary 1 Normal Technical (Sec 1NT) Maths Curriculum. Utilising Braun and Clarke's thematic analysis, the study identified key themes that highlighted students' understanding of mathematical concepts, their strategic approaches to problem-solving and the underlying challenges they faced. Notably, learners demonstrated an ability to articulate their thought processes and apply familiar strategies. However, they struggled with confidence and the exploration of alternative methods.

The findings aligned with Schraw and Moshman's metacognitive frameworks, emphasising the importance of understanding the various stages of learners' problem-solving processes (Schraw & Moshman, 1995). This understanding was particularly crucial for learners with dyslexia, who may encounter unique challenges in both reading mathematical language and applying mathematical concepts (Butterworth, Varma, & Laurillard, 2011). By recognising the specific stages at which these learners struggle, educators can tailor instructional methods to address their needs, thereby enhancing their metacognitive awareness and problem-solving capabilities.

Recommendations include employing informal assessments to identify gaps in metacognitive skills before introducing new topics. Many secondary school concepts can be abstract and challenging, making this approach vital for all learners, especially those with learning differences like dyslexia (Gersten, Beckmann, Clarke, Foegen, Marsh, Star, & Witzel, 2009). Implementing structured problem-solving frameworks, such as Polya's method (2004), within the secondary mathematics curriculum can provide learners with dyslexia the structured support they need to navigate mathematical problems more effectively, ultimately improving their confidence and proficiency in mathematics.

While the study was exploratory in nature, its findings contributed to a deeper understanding of how learners with dyslexia approach mathematical tasks and the types of support that may enhance their confidence and independence. Future research that expands the learner profile and problem contexts will strengthen and extend these insights.

In conclusion, this research contributes to the growing body of literature on metacognition in mathematics education, particularly for learners with dyslexia. By acknowledging these learners' metacognitive challenges and leveraging frameworks for understanding their processes, educators can better support students in their

mathematical journey. This targeted approach not only aims to improve outcomes in mathematics education but also fosters a more inclusive learning environment that empowers all students, ensuring they have the tools necessary for academic success.

REFERENCES

- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Publishing
- Birt, L., Scott, S., Cavers, D., Campbell, C., & Walter, F. (2016). Member checking: A tool to enhance trustworthiness or merely a nod to validation? *Qualitative Health Research, 26*(13), 1802–1811.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.
- Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*(3), 273–293.
- Butterworth, B., Varma, S., & Laurillard, D. (2011). Dyscalculia: From brain to education. *Science, 332*(6033), 1049–1053.
- Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school students: The effect of a training programme focusing on metacognition and working memory. *British Journal of Educational Psychology, 85*(3), 424–439.
- Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education, 3*(2), 63–68.
- Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches* (3rd ed.). SAGE.
- Desoete, A., Roeyers, H., & Buysse, A. (2001). Metacognition and mathematical problem solving in grade 3. *Journal of Learning Disabilities, 34*(5), 435–447.
- Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest, 14*(1), 4–58.
- Efklides, A. (2011). Interactions of metacognition with motivation and affect in self-regulated learning: The MASRL model. *Educational Psychologist, 46*(1), 6–25.
- Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*(10), 906–911.
- Gersten, R., Beckmann, S., Clarke, B., Foegen, A., Marsh, L., Star, J. R., & Witzel, B. (2009). *Assisting students struggling with mathematics: Response to intervention (RTI) for elementary and middle schools* (NCEE 2009-4060). What Works Clearinghouse.
- Gersten, R., Jordan, N. C., & Flojo, J. R. (2005). Early identification and interventions for students with mathematics difficulties. *Journal of Learning Disabilities, 38*(4), 293–304.
- Gregory, I. (2003). *Ethics in research*. Continuum.
- Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology, 39*(3), 281–291.
- Kramarski, B., & Mevarech, Z. R. (2003). Enhancing mathematical reasoning in the classroom: The effects of cooperative learning and metacognitive training. *American Educational Research Journal, 40*(1), 281–310.

- Lapadat, J. C., & Lindsay, A. C. (1999). Transcription in research and practice: From standardization of technique to interpretive positionings. *Qualitative Inquiry*, 5(1), 64–86.
- Mevarech, Z. R., & Amrany, C. (2008). Immediate and delayed effects of meta-cognitive instruction on regulation of cognition and mathematics achievement. *Metacognition and Learning*, 3, 147–157.
- Montague, M. (2008). Self-regulation strategies to improve mathematical problem solving for students with learning disabilities. *Learning Disability Quarterly*, 31(1), 37–44.
- Polya, G. (2004). *How to solve it: A new aspect of mathematical method*. Princeton University Press.
- Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review*, 7, 351–371.
- Schoenfeld, A. H. (2016). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics. *Journal of Education*, 196(2), 1–38.
- Snowling, M. J. (2012). Changing concepts of dyslexia: Nature, treatment and comorbidity. *Journal of Child Psychology and Psychiatry*, 53(9), e1–e3.
- Stanton, J. D., Sebesta, A. J., & Dunlosky, J. (2021). Fostering metacognition to support student learning and performance. *CBE—Life Sciences Education*, 20(2), fe3.
- Suri, H. (2011). Purposeful sampling in qualitative research synthesis. *Qualitative Research Journal*, 11(2), 63–75.
- Tay, S. S. (2023). *Secondary 2 (Normal Technical) maths topical revision* (4th ed.). Education Publishing House.
- Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, 45(1), 2–40.
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2), 64–70.

APPENDIX: MATHEMATICAL TASK

In a factory, 4 workers take 2 hours to assemble 15 wardrobes.
Find the amount of time 6 workers will take to assemble 15 wardrobes.

Give your answers in hours and minutes.

Answer: _____ h _____ min

Source:

Tay, S. S. (2023), Secondary 2 (Normal Technical) Maths Topical Revision 4th Edition.
Education Publishing House Pte Ltd. Question 6 of End of Year Revision Paper