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How to Effectively Support Students with Dyscalculia

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HOW TO EFFECTIVELY SUPPORT STUDENTS WITH DYSCALCULIA

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ABSTRACT

Dyscalculia is a neurodevelopmental disorder, which makes it difficult for some individuals to automatically recognize numbers, estimate, perceive pictures, and order items and procedures correctly. It is similar to dyslexia, a common comorbidity, but it is focused on math difficulties rather than reading. Predispositions for dyscalculia may include differences in brain functioning, familial prevalence, and preterm birth. Dyscalculia persists through adulthood and is often resistant to most interventions. When a student with dyscalculia qualifies for special education services, it is most likely under the label specific learning disability in the area of math. As districts push to keep as many students in the general education classes as possible, there has been a rise of co-taught classrooms including special education teachers who work along with the academic content teachers. These teachers need increased training and knowledge, which can help them implement effective instruction and accommodations for students with dyscalculia. Effective strategies include hands-on math manipulatives, graphic organizers, an organizational system which is easy to understand, explicitly-taught concrete to abstract numerosity training, and accommodations to assessments that help students understand the questions. A chapter plan from a specific curriculum is included along with a list of accommodations that can help students with dyscalculia gain confidence in their math ability.

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CHAPTER I: INTRODUCTION

Dyscalculia

It is not uncommon for a student to express that they hate math. In fact, many adults say similar phrases without showing any remorse or regret on the subject. While this may be true, many of those same students and adults have never heard the term dyscalculia, which could be the specific reason they struggled in math. The topic of this thesis is focused around the term dyscalculia. The American Psychiatric Association (2022) describes dyscalculia as a specific learning disorder in mathematics where an individual struggles with "...number related concepts or using the symbols and functions to perform math calculations" (p. 13). They go on to describe it as a neurodevelopmental disorder along with dyslexia, struggles in reading, and dysgraphia, struggles in writing and how each disorder can be categorized as mild, moderate, or severe. It is estimated that these neurodevelopmental disorders may affect 5% to 15% of school-age children and that these difficulties persist into adulthood (American Psychiatric Association, 2022).

One researcher described dyscalculia as a term used to describe "a disorder in which normally intelligent children demonstrate specific disabilities in learning mathematics" (Michaelson et al., 2007, p. 7). As described above, a quick way to help someone understand this concept is to explain that dyscalculia is similar to dyslexia, a more commonly understood term, but for math instead of reading. In fact, there may be reason to believe dyscalculia may just be one aspect of dyslexia (Andersson et al., 2021).

While dyscalculia is the medical term used to diagnose individuals, in the special education realm students with more moderate to severe dyscalculia often receive services under the label of specific learning disability in the area of math (SLD or SLDM) or a math learning disability (MLD). The studies in this thesis will include some of these acronyms along with developmental dyscalculia (DD), which they use to describe individuals who struggle in math to the extent that they met the specific criteria for their specific study.

While defining common language is helpful, the most important aspect of dyscalculia is how to best help those students be successful in math. Effective strategies and accommodations could help students build stamina and confidence with math, given the appropriate supports, instead of categorizing it as their least favorite subject. If more teachers understand dyscalculia and the possible interventions and strategies, which have shown to be effective, then the students with whom they work will benefit in their math learning and confidence which could have long lasting effects in their future careers.

In the United States' educational system, many of these individuals will qualify for special education services, however, not all students will qualify, nor will all of the special education students be taken out of the general education setting. In the past, most special education students who struggled in math received their math instruction in a pull-out or resource setting, whereas it is becoming more common for the students to stay in the general education classes and receive accommodations or modifications to help them access grade level content. Due to keeping more and more students in the general education setting, districts are including more co-taught classes where special education teachers are pushed into the general education classes. This makes for a more ideal teacher to student ratio in the class while also providing an opportunity for classes to be strategic with grouping and instruction, helping more students find success in each new math skill, showing students valuable collaboration skills, and for teachers to learn new approaches from each other (Kirkpatrick et al., 2020). While this can be an effective school strategy, not all teachers have the best training nor do they understand dyscalculia and the best strategies to help these students. The focus of this literature review will be to discover how general and special education teachers can collaborate to support students with dyscalculia.

It is important to acknowledge that most of the language surrounding this topic is deficit-based, with which a growing number of people take issue (American Psychiatric Association, 2022). One success story as detailed in Lewis et al. case study (2018), shared how a student with dyscalculia grew up to become a statistician, a career which necessitates quite a bit of high level math. In that article, the researcher shared that using deficit based language can be hurtful and suggested using language like learning differences rather than learning disabilities (Lewis et al., 2018). Throughout this thesis, deficit based language is included, however, it is not the intention of this researcher to suggest that individuals with dyscalculia are any less capable than a typically developing learner of achieving at high levels in math. In fact, it is the goal of this research to help equip teachers in helping students with dyscalculia to do just that.

Thesis Writer Experience

This thesis author has worked in the Richfield Public School District (MN, United States) as a special education teacher for her whole teaching career. She specializes in the area of math and began teaching in a co-taught math setting in general education early in her teaching career. This writer quickly noticed some specific ways that special education students struggled to grasp new math concepts, recall previous topics, and to solve problems with correct procedures. The students with special education needs in math in this setting have qualified for special education services under multiple special education labels including Emotional/Behavioral Disorder (EBD), Specific Learning Disability (SLD), and Autism Spectrum Disorder (ASD), however, most of the students receiving special education service in the co-taught math setting are labeled having SLD. Together with her co-teacher, this author implemented interventions and strategies to help students who were struggling in math have more success. Interventions were implemented such as individualized grouping methods, organizational systems, graphic organizers for vocabulary and math processes, testing accommodations, modified tests for individuals, and timely formative data collection. Each year, this writer and her co-teacher assessed and reassessed what worked and which strategies needed to be updated to best support students who struggled in math.

In 2018, Richfield Public Schools adopted a new math curriculum for grades 6 through 12 named College Prep Math (CPM) (Dietiker et al., 2022). This curriculum has brought new challenges and opportunities for the math department as well as the special education teachers and English language (EL) teachers who co-teach in the math courses. CPM as an organization is strong in its support and training of teachers in the curriculum. This researcher was given training alongside her co-teacher in the CPM Core Connections Algebra (CCA) curriculum (Dietiker et al., 2022) during the summer previous to implementation of the curriculum. The curriculum shifted away from direct teaching and towards small group collaborative learning through discovery and highly encouraged productive struggle. It is important to tell the difference between when a group is productively struggling and has not yet tried all of their ideas, versus when a group is completely lost and does not know where to start. Many team study strategies were encouraged so the students could learn together and have many opportunities to talk through their math understanding. While this author continued to collaborate with her co-teacher and found many new exciting strategies, she found it more difficult to support struggling students within the bounds of the curriculum and the emphasis of teaching the curriculum with fidelity. This writer has been especially concerned for her students with the label of SLD who have suspected struggling with dyscalculia.

As this author grows in her development as a special education teacher in math, she is more interested in researching dyscalculia, how it presents in students' understanding and work, and the most effective ways to help these students. This researcher is excited about the challenge of integrating her findings with the math curriculum. She is especially excited to share her ideas with the math department, science department, and special education department, as well as the building instructional leadership team (BILT) of which this writer is a member. Most importantly, this writer is deeply invested in helping her students not only pass their math class, but thrive and see that they can be proud of the work they accomplish despite any setbacks they may perceive.

Key Terms

Magnitude

In math, magnitude is used to describe the physical size of objects or the amount of any substance or force. It is used to compare which object is bigger, or has more items, or is faster or stronger. Some of the tasks measured in different studies include magnitude comparison tasks (Mammarella et al, 2021; Morsanyi et al., 2018; Rubinstein et al., 2006).

Approximate Number System (ANS)

The approximate number system is related to magnitude, but slightly more narrowed in meaning. It is focused on the numerical values and how far apart or close together the numbers are. It can also focus on a list of numbers or amounts and estimating where they would be placed on a number line. Some studies use approximate number system acuity tasks to see if students can correctly estimate whether a middle number is closer in distance to the higher or lower number (Mazzocco et al., 2011; Cheng et al., 2020).

Visual Perception

Visual perception involves what an individual sees and how they perceive what they see. In the Cheng et al. study (2018), the researchers measure visual perception by measuring choice reaction time to see how quickly the participants could distinguish an item being on the left or right, a mental rotation task, visual tracing task where the participants trace a line through other squiggly lines to find the endpoint with their eyes only, and a figure matching task.

Thesis Question

The guiding research question for this thesis is: **How can general and special education teachers effectively support students with dyscalculia?**

The first aspect that will be addressed is what dyscalculia is and how it affects students' learning including predictors and indicators. It is important to understand the main indicators that show an individual has dyscalculia as well as situations which may predispose individuals to the disorder.

Another aspect will focus on how comorbidities, simultaneous disorders that individuals may have, affect dyscalculia, especially dyslexia. It is important for teachers to understand how comorbidities may or may not affect a student's math level. The last aspects addressed will focus on the general education setting and specific strategies that have been shown to be effective according to empirical data and case studies. The knowledge gained from these strategies will help inform teachers of possible instructional practices, supports, and accommodations that may be beneficial. Once this information is discovered and laid out, the application emphasis will build an instructional unit for a specific school using a general education curriculum to enhance math learning for students with dyscalculia/MLD in a co-taught setting.

CHAPTER II: LITERATURE REVIEW

Information Gathering Process

Resources for this thesis were gathered mostly through the Bethel University Reference Library using the Academic Search Premier database and the ERIC database. Keywords used for searches included singular and combinations of the following words: “dyscalculia”, “math disability”, “secondary”, “interventions”, “team teaching”, “co-teaching”, “co-taught classes”, “least restrictive environment”, “instruction”, “accommodations”, “modifications”, “algebra”, “learning disability”, “comorbidities”, and “dyslexia”. All searches were narrowed down to articles which were peer reviewed and had the full text available and were found during June and July of 2022. Search parameters included journal articles written between 1997 and 2021. International studies were included and helpful in this research. Studies with participants whose ages ranged from birth through college age were included and pertinent to show the effects of dyscalculia at different ages.

Predictors

Research shows that dyscalculia may have antecedents or predictors which could either cause or indicate whether an individual has the math disability. One study by Adrian et al (2020) looked at preterm birth as a possible antecedent of low math skills in children. This longitudinal quantitative study aimed to measure math levels in specific areas rather than math skills as a whole and to see which areas were most likely affected by their preterm birth. The researchers measured the math levels in many different areas in an experiment and control group spanning over three years when the children were five, six and seven years old. In total, the study included 78 participants, 51 children who were born preterm (24-32 weeks gestation) and 27 children born full-term (38-41 weeks gestation). The experiment and control groups had no significant differences in age at testing, sex, household income, race nor ethnicity. There was an intentional difference in gestational age at birth, which led to a significant birth weight difference. The researchers also found that the level of education of the children's mothers in the experimental group was lower than those in the full term birth control group. They took note of that difference and were careful to acknowledge its effect on the outcomes and adjust accordingly. None of the children chosen had any severe congenital, physical, or neurological disabilities. The children for the experimental group were recruited primarily from UC San Diego High-Risk Infant Follow Up Clinic while the children for the control group were recruited through the Center for Human Development at UC San Diego. Written informed consent from legal guardians was given (Adrian et al., 2020).

The instrumentation and procedures for the study included "a comprehensive battery of cognitive and academic tests, health and demographic questionnaires and magnetic resonance imaging (MRI) at three time points at approximate ages of 5, 6, and 7 years" (Adrian et al., 2020, p. 838). The math skills were tested using the third edition of the Test for Early Mathematics Ability (TEMA-3), which is standardized based on age and performance and were split into the two categories of number skills including verbal counting, counting objects, and numerical comparison versus arithmetic skills, which included division problems in story or money form, story form calculation, and addition number facts. The cognitive assessment included tests for spatial working memory, inhibitory control, visual-motor integration, and phonological processing. The results, adjusted for maternal education, indicated lower overall math skills and cognitive functions in the preterm children compared to the children born at full term at each age. More specifically, results showed that the difference in number skills decreased as the children aged showing a closing gap whereas the difference in arithmetic skills increased as the children got older showing a widening gap. Adrian et al suggested “[l]ower arithmetic skills may arise from lower number skills if number skills act as a scaffold to promote learning of arithmetic skills" (p. 849). Overall, results showed math skills are affected by preterm birth and that arithmetic skills may grow in discrepancies as children get older (Adrian et al., 2020).

A different recent study by Kuhl et al in 2021 also focused on the early aspects of brain development in children with dyscalculia. This longitudinal mixed methods study used MRI scans of children three to six years old and followed them until they were seven to nine years old, and compared the scans of those identified as having dyscalculia and those who do not. The researchers had the hypothesis that there would be significant differences between the experimental and control groups’ brains in the parietal and prefrontal cortices. The researchers identified 15 children who developed dyscalculia by scoring at least one standard deviation (SD) below the mean as the experimental group and matched them with “... 15 typically developing children to minimize differences in age, sex, handedness, maternal education, language ability, nonverbal intelligence quotient (IQ), and verbal short-term memory” (p. 2). They were careful to get baseline data before the children received any formal math instruction so the results could not be seen as a result of types of instruction (Kuhl et al., 2021).

Methods used in the Kuhl et al study (2021) included an MRI looking at the childrens’ regional functional activity and network-level functional connectivity when they were three to six years old and again when they were seven to nine. They also used questionnaires to establish the educational levels of the mother, the Wechsler Intelligence Scale for Children for the nonverbal IQ score, and the Edinburgh Handedness Inventory adapted for children. For math scores, the Heidelberg Calculation test was used and the researchers were specifically interested in the scores of the visuospatial numerosity and calculation problem solving subtests to help establish dyscalculia. The researchers found that their hypothesis was true because their results indicated "...identified a neurobiological early childhood predisposition for dyscalculia characterized by altered spontaneous activity, functional interaction, and structural connectivity of a frontoparietal network in the developing brain" (p. 9). The frontoparietal network of the brain includes the parietal and prefrontal cortices and the connections between the regions is known to send numerosity and calculation information back and forth. This study showed that a reduction in activity between the cortices in early childhood could indicate a predisposition for dyscalculia before any formal math instruction has been attempted (Kuhl et al., 2021).

While parts of the brain seem to be affected by dyscalculia, a different study wanted to determine whether those with a math learning disability (MLD) have other core deficits in their cognitive functions (Mammarella et al., 2021). The quantitative study tested two hypotheses: the first was the null hypothesis, which stated that individuals with MLD would have a core deficit in their basic number processing skills while the second hypothesis was that those same children would have many impairments in their cognitive skills beyond math. The study first tested 1,303 students from 73 classes in grades two, three, and four. Students with incomplete data, intellectual disabilities, and low reading ability. The experimental group had 47 participants and were those considered MLD whose math scores were in the 10th percentile or lower while the rest of the 895 students who did not have other exclusion factors were considered the control group (Mammarella et al., 2021).

The Mammarella et al study (2021) took many test measures for the students in three testing sessions within five months. The tests included measuring math achievement, a reading task from a clinical battery, which assesses dyslexia, fluid intelligence, magnitude representation and comparison, and working memory. After using rigorous comparison between the two groups, the researchers concluded that neither hypothesis was true. They found that "individuals with MLD may have deficits in both basic number processing and in domain-general cognitive skills, but neither of these are necessarily present" (p. 710). They suggested that differences in cognitive outcomes would more likely be associated with a potential comorbidity with another disability or severity of the disorder rather than the presence of MLD in individuals (Mammarella et al., 2021).

Another possibility was studied by Shalev et al. (2001) when they learned whether familial connection could predict the chances of getting dyscalculia (DC). This quantitative study hypothesized that there would be a significant correlation between individuals with DC and the prevalence of the disorder in family members. There were two DC groups as a part of this study done in Israel. Participants for the first group included 46 children from 33 families who met the DC qualification persistently over a three year period and it excluded children who had comorbidities of ADHD, dyslexia, and dysgraphia. The family members of those individuals included 19 fathers, 28 mothers, 73 siblings, and 6 second degree relatives. For the second group, six individuals were identified with a similar process to have DC and 12 of their parents and 23 siblings agreed to participate in the study. Differences between the groups were that the first group was lower middle class families while the second was middle class (Shalev et al., 2001).

This genetics study (Shalev et al., 2001) had assessments which were carried out by trained personnel from a neuropediatric unit at Shaare Zedek Medical Center. Each participant was individually assessed using an age-standardized test of arithmetic skills, a Wide Range Achievement Test-Revised (WRAT-R), standardized reading test for exclusion purposes, a child behavior checklist, and a Wender Utah Rating Scale questionnaire for ADHD, and standardized IQ tests for children and adults. The researchers found that around 53% of immediate family members had DC as well as 43% of second degree relatives. They concluded that, similar to other learning disabilities, dyscalculia has "...a familial predisposition" (p. 62) based on their findings that family members of children with DC are almost ten time more likely to also have DC than the 6% prevalence of the general population (Shalev et al., 2001). This compelling evidence shows another predictor of dyscalculia.

These four studies (Adrian et al., 2020; Kuhl et al., 2021; Mammarella et al., 2021; Shalev et al., 2001) helped teachers and other individuals understand what may or may not be included as predictors of dyscalculia and math learning disabilities. Whereas Mammarella et al indicated core deficits were not predictive of MLD (2021), the other studies suggested preterm birth (Adrian et al., 2020), differences in childrens' frontoparietal network in their brain (Kuhl et al., 2021), and familial prevalence of the disorder (Shalev et al., 2001) could predispose them to significant struggles in the area of math. These ideas laid the foundation of understanding how students' brains can make learning math specifically more difficult than other tasks and help teachers understand some individuals may need significant support especially in the regular rigor general education math setting.

Indicators

While possible predispositions are important to be aware of, the main indicators of dyscalculia help teachers and other adults identify students who may need more intense interventions and possibly special education services. A study by Cheng et al. (2018) hypothesized that visual perception plays a role in the arithmetic deficits found in individuals with dyscalculia, dyslexia, and those with both disorders. This quantitative study drew from 1,142 third to fifth grade students from five primary schools in Beijing. All students were native Mandarin speakers and had normal vision or had appropriate eyewear, which gave them normal eyesight. Written informed consent was obtained for all participants. Participants were labeled with dyscalculia or dyslexia if they scored lower than the 7th percentile in their respective areas of need and above the 25th percentile for intelligence. If they qualified in both reading and math, they were designated into the comorbidity group. There were 39 students in the dyslexia group, 48 in the dyscalculia group, 18 for the comorbidity group, and 48 chosen for the typically developing group who were individually matched with the other group based on age, gender, and grade but scored above the 7th percentile in reading and arithmetic (Cheng et al., 2018).

The tasks measured for this study (Cheng et al., 2018) were given over two 45 minute sessions individually and on a computer. The tasks included sentence completion, subtraction, choice reaction time, mental rotation, nonverbal matrix reasoning, visual tracing, numerosity comparison, figure matching, and data analysis. Cheng et al. listed choice reaction time, mental rotation, visual tracing and figure matching as the tasks to represent visual perception, but especially the figure matching task. The researchers found significant differences in all three experimental groups compared to the control group in numerosity processing and visual perception leading them to conclude that visual perception is indeed an indicator for dyslexia and dyscalculia groups (Cheng et al., 2018).

A quantitative study by Mazzocco et al. in 2011 proposed the hypothesis that dyscalculia is contributed to by a poor approximate number system (ANS) rather than poor working memory or other domain-general cognitive deficits. Another question the researchers had was how classifying the participants into the more profound MLD (<10th percentile) and the individuals who were low achieving (LA) (11th to 25th percentile) would interact with the potential ANS deficiency. Their hypothesis was that individuals with more significant math struggles (MLD) would show an indicator of poorer ANS which would differentiate them from not only the typical (TA) and high achieving (HA) math students but also the relatively lower achieving (LA) math students in the 11th to 25th percentile. The study recruited ninth grade students from the Baltimore County Public Schools district and excluded students whose high mobility and eligibility for free and reduced lunch implicated higher poverty rates, which the researchers felt could skew the data. Another exclusion factor included students whose math achievement scores were inconsistent over time. Out of the 71 participants, 10 students were selected for the MLD group, 9 for the LA group, 37 for the TA group (25th to 95th percentile), and 15 for the HA group (>95th percentile) (Mazzocco et al., 2011).

The testing measures used for the Mazzocco et al study (2011) included two ANS tests; one of the tests measured non-symbolic approximations where the individual decided which picture had more items whereas the other was a symbolic number task comparing written numbers. The researchers also used the data of two standardized math tests previously administered, Test for Early Mathematics Ability (TEMA-2) and the Woodcock Johnson Revised Calculation subtest (WJR-Calc). The data from an arithmetic test called the Fast Math Test or FMT was also retrieved from the students' eighth grade year, which involved one or two digit arithmetic problems and had a time component. Finally, the researchers also included some general cognition tests measuring lexical retrieval speed, visual perceptual skills, memory, working memory, and spatial memory. The researchers determined that "... MLD derives, at least in part, from a domain-specific deficit in the ANS" (p. 1234). Furthermore, the researchers were able to determine that combining the MLD students with the LA students was inadvisable due to determining that the ANS measures between the LA and TA groups were indistinguishable (Mazzocco et al., 2011).

A recent study from 2018 had a purpose to "…conduct a systematic investigation into ordering skills in children with DD [developmental dyscalculia]" (Morsanyi et al., 2018). The researchers also wanted to determine if those deficits are present in familiar and novel sequences as well as non-numerical tasks. This quantitative study hypothesized that individuals do have an order processing deficit. Their study believed itself to be "conducting the most comprehensive investigation into order processing skills in DD so far…" (p. 599). First, drawing from 19 potential urban and rural schools from Northern Ireland, the researchers used selective procedures to choose 20 children with developmental dyscalculia and 20 children without math difficulties by using standardized test scores in math and English as well as IQ scores. Between the two groups, they chose students who had similar socio-economic levels, ages, genders, classes, reading ability, and IQs (Morsanyi et al., 2018).

Once the study groups were solidified, Morsanyi et al (2018) used the same procedures for each of the individuals in three testing sessions. The tasks included a variety of measures in order processing, ordinal judgment, magnitude and estimation, and inhibition. A Likert scale was used with a parent questionnaire. During most of these tasks, the researchers also measured reaction time as an additional variable. The researchers found a significant difference between the two groups' outcomes in the order processing, ordinal judgment, and magnitude and estimation; however, the most significant indicator was the order processing. They found that this was evident in numerical as well as non-numerical tasks and familiar and novel sequences. They drew the conclusion that order processing deficits are a major underlying predictor of dyscalculia in individuals (Morsanyi et al., 2018).

These three studies highlighted important indicators for students with MLD or dyscalculia. The first concluded that visual perception deficits were an underlying contributor

(Cheng et al., 2018), the second sought to determine if the Approximate Number System contributed to dyscalculia (Mazzocco et al., 2011), and the third included measures of order processing as another deficit (Morsanyi et al., 2018). It is important to note that the study by Morsanyi et al. (2018) agreed with the former study by Mazzocco et al. (2011) that ANS is a strong indicator, but concluded that the order processing had a stronger correlation. Accommodations and instructional changes can be tailored with these indicators in mind.

Dyslexia and Other Comorbidities

While some people have been diagnosed with dyscalculia only, there are some important comorbidities that seem commonly associated with dyscalculia. In their study, Hachmann et al. (2014) focused on order processing in individuals with dyslexia rather than the Morsanyi et al. study (2018) on dyscalculia above. The purpose of this study was to determine whether short-term memory tasks were impaired for order processing as well as item recognition. The researchers hypothesized that the order processing would indeed be impaired while the item recognition would be similar to control groups. There were 52 participants in this study from Ghent University in Belgium. All participants were native Dutch speakers and half of them had a certified diagnosis of dyslexia, which were the experimental group while the other half, the control group, was chosen to match the experimental group in demographics, sex, and IQ levels but had average or above average reading levels (Hachmann et al., 2014).

The tasks set forth by Hachmann et al. (2014) included a verbal and non-verbal item task and a verbal and nonverbal ordering task. For the item tasks, participants were shown 13 pictures for a given amount of time and then had to answer “yes” or “no” to whether the item had been a part of the group of pictures. The verbal aspect included a voice naming a potential picture whereas the non-verbal aspect was seeing another potential picture and deciding whether it matched the original group of pictures. For the verbal order task, individuals were given a list of the digits one through nine in mixed order and then asked to determine if a list had the same order. Finally, for the nonverbal order task, individuals were given distinguishable symbols, which had no identifiable word associated with them, in specific order and once again had to determine if the next set was in the same order. The researchers found that the experimental group got similar scores in the item identification, but scored significantly lower in both the verbal and non-verbal ordering tasks (Hachmann et al., 2014). This showed that dyslexia has an order processing deficit similar to dyscalculia.

One study by Peters et al. in 2018 studied the brain activity in people with dyscalculia, dyslexia, both, and those without either neurodevelopmental disorder. The researchers believed themselves to be the first to do this specific study. This quantitative study had two hypotheses: the first was that children with dyscalculia would have neural differences from the control group in all of the tasks and the second was that children with dyslexia would have neural differences with the control group when given symbolic tasks, but not the non-symbolic tasks. There were 62 participants ages ranging from 9 to 12. Those with diagnosed specific learning disabilities of dyslexia (DL), dyscalculia (DC), or both (DLDC) numbered 39 participants versus the control group (TD) with 23. None of the participants had additional diagnoses beyond the DL and DC. In addition to the diagnoses, the researchers validated each diagnosis by administering additional standardized tests for arithmetic and reading ability (Peters et al., 2018).

Peters et al. (2018) used MRI scanning while giving children arithmetic tasks in symbolic and non-symbolic formats. These included questions with dot arrays, word numbers, and digits. The researchers found that the TD children were faster in responding to each task than students with learning disorders while those with the comorbidity (DLDC) had the slowest responding time. They also found that when it came to accuracy scores, the groups scored as expected with the DC and DLDC group scoring lowest overall since all tasks were arithmetic while the DL group scored lower with the tasks with word numbers. In terms of the brain, the researchers found that the neural activity found in the DC, DL and DLDC groups were very similar to each other whereas the control group had higher activation levels in the frontoparietal region. This shows that there are significant neural similarities between children with dyslexia and dyscalculia in the frontoparietal region of the brain (Peters et al., 2018).

An earlier study conducted in Israel by Rubinstein et al. (2006) also noted similarities between dyslexia and dyscalculia. This study's purpose was to "... determine whether people suffering from developmental learning disabilities have a general difficulty in automatically associating symbols with their mental representations, or is this difficulty specific to letters in the case of dyslexia and to digits in the case of dyscalculia" (p. 855-856). The study focused on college aged students at Ben-Gurion University and had a total of 51 participants, 17 individuals in each group who were designated as those with a diagnosis of developmental dyscalculia, developmental dyslexia, and the control group, which had neither diagnosis. Those with a comorbidity of the two neurodevelopmental disorders were excluded from the study and each group's average IQ was between 100 and 109 (Rubinstein et al., 2006).

The Rubinstein et al. study (2006) ran two experiments. The first experiment was to compare the value of numbers and magnitude (size) of numbers. The experiment mixed up the size and values of single digits and the participants had to first choose which number was larger and then which number was greater in value. The participants' reaction time (RT) was measured to assess automaticity and they were asked to answer as quickly as they could. The results of this experiment showed that the group with developmental dyscalculia had the slowest RT, while the group with dyslexia was faster and the control group was the fastest. The second experiment also had two tasks, which were focused on letters. Hebrew letters, which were the first language of all participants, were designed with small letters, which were shaped into a large letter. For one task, the participants were instructed to name the small letters and for the other, participants were to name the large letter. The outcome of this experiment showed that those with developmental dyslexia had the longest RT whereas the other two groups were much faster with the control group having the fastest RT. The researchers concluded that the dyscalculia population has difficulties in automatically associating numbers and sizes but no problems in associating letters with phonemes, whereas the dyslexia population shows the opposite pattern (Rubinstein et al., 2006).

An earlier study (Shalev et al., 1997) aimed to show whether students with comorbidities of development dyscalculia (DD) and reading, spelling, and attention deficit hyperactive disorder (ADHD) had different levels of math ability from those with no comorbidities. This quantitative study had two hypotheses: the first was focused on whether students with the comorbidity of reading and spelling problems (RS) had better arithmetic skills than those with DD only and the second was similar but compared those with and without the comorbidity of ADHD. The participants in this study were all students whose standardized test scores showed they were in the average range for IQ but had a history of low math scores and were specifically below the mean of students who were two grades behind. In total, 139 participants met the criteria and whose parents consented for further testing. The grouping for the first hypothesis included 35 students with a comorbidity of DD and RS, while those with typical reading skills numbered 104. There were a similar proportion of students with ADHD, gender, socioeconomic status and performance IQ. The second hypothesis separated the students into three groups including 84 with DD only, 28 with DD and ADHD, and 17 with DD and RS; there were some individuals whose scores were excluded from testing in this hypothesis due to comorbidities in all areas. There were similar demographic balances in this breakdown as well (Shalev et al., 1997).

Methods used for this Shalev et al. study (1997) included "neuropsychological measures tapping executive functions, language-sequential skills, and visuo-spatial tasks" (p. 107). The tests were all individual and the administrator and observer did not know which category the students fit into for either hypothesis creating a double blind to cut down on bias. The researchers found that their first hypotheses was incorrect and that students who had a comorbidity of reading and spelling troubles had overall lower arithmetic scores and noted "[i]t should not be surprising that children who have more than one brain-based disorder are the most profoundly affected" (p. 117). For the second hypothesis, the results showed that the group with DD and ADHD had a non-significant difference in arithmetic score whereas the group with the comorbidity with reading difficulties was still the lowest score overall. Although neither of their hypotheses were correct, they were able to gather valuable information about dyscalculia and how common comorbidities may or may not affect their math scores (Shalev et al., 1997).

Another comorbidity was included in a more recent study, which looked at the prevalence and relationship between math performance for dyscalculia (DD) and math anxiety (MA) (Devine et al., 2018). The study looked at a sample size of 1,757 students in southeast England primary and secondary schools from urban and rural areas. They chose schools with higher percentages of needing free meals and schools with lower percentages as well. The schools varied in the representation of students with special education services and English as a second language service; those students were included in the data to increase the representative sample (Devine et al., 2018).

To measure math anxiety, Devine and the other researchers used a self-reporting questionnaire, which used a 1-5 Likert scale. The mathematics level was measured using a standardized math test, and their reading and writing were measured using standardized tests as well in paper form. All tests were given in group settings with distance and multiple versions to ensure no students would benefit from a student nearby. The researchers reported a strong statement with their findings:

> This study shows that about one fifth of children meeting criteria for developmental dyscalculia are also highly anxious about mathematics. Yet, the majority of children with high mathematics anxiety have adequate or even high mathematics performance. These findings suggest that for the most part, each of these math learning problems needs to be treated separately… (Devine et al., 2018, p. 431)

This shows that math anxiety may not be correlated with a student's math ability or disability.

These studies of dyslexia and other comorbidities above help develop a broader understanding of dyscalculia. The Hachmann et al. study (2014) focused on the order processing impairment in individuals with dyslexia, which when paired with the Morsanyi et al. (2018) finding a similar indicator in individuals with dyscalculia, shows another bond between the two disorders. In the Peters et al. study (2018), it was established that there are similarities between the brain activity with those who have dyslexia versus dyscalculia. The next study (Rubinstein et al., 2006) showed an opposite but similar pattern in automatic recognition of numbers and letters for people with dyscalculia and dyslexia respectively, which shows a further link between the two. Finally, findings show that a comorbidity of a reading disability or struggles can lower an individuals' math level even lower than those without reading difficulties (Shalev et al., 1997) but that math anxiety is not a predictor of math performance (Devine et al., 2018). Overall, it is important to know more about dyscalculia, how it presents and how educators can help students grow in their math understanding despite the difficulties present.

Team Taught Setting

In special education, each individual is entitled to a yearly meeting in which the team discusses what the least restrictive environment (LRE) is for the student. The goal of the team is to keep the student with their non-disabled peers in the general education setting, also known as an inclusive setting, as much as possible. This emphasis has led to districts incorporating more inclusive settings where students take general education classes, but there is a special education teacher in the classroom as well as the academic content teacher. The goal of this intervention is for the special education teacher to be highly focused on strategies such as implementing interventions, adapting curriculum, collaborating to enhance best instructional practices, and lowering the student to teacher ratio that benefits the students with special education services.

In a quantitative study from 2015, a study by Cramer focused on looking at an unnamed large urban school district in the US and the shift towards more inclusive settings. Cramer noted that urban districts lag behind suburban counterparts in the percent of students participating in the general education setting for most of the day.

> This study examined the inclusion rates (based upon the 80% of the school day criteria), average time spent with nondisabled peers, reading achievement, and math achievement of students with and without disabilities at 56 schools before and after a thorough review process that took place during the 2013 -2014 school year in one large urban school district. The review process that took place was the LRE/Achievement at a Glance review process. (p. 41)

The review process was a tool used to help the district move towards being more inclusive and helping students achieve at a higher rate. The tool included nine domains: program delivery, inclusion practices, learning areas, materials, assessment, instruction delivery, behavior, parent involvement, and professional development (Cramer, 2015).

Methods used in this review process by Cramer (2015) had four parts spread over two years including baseline data collection, observations with LRE/Achievement at a Glance tool, a compilation of the review, and a meeting with the school site administration. Cramer revealed that in the two year span, the inclusion rate of at least 80% of the day in the general education for students with special education services jumped from 50% to 68%, which was a significant increase. During that time, the math and reading scores were maintained but did not increase. Cramer suggested that academic increases may show up with a longer study, but that the fact that students were not hindered by the general education setting suggested that it was the correct placement for most of the individuals (Cramer, 2015).

Barrocos et al. (2014) ran a similar study with a slightly narrowed scope. This quantitative study also studied an urban population district and the effects on reading and math achievement in inclusive versus non-inclusive settings, but it specifically focused on low socio-economic Hispanic middle school students with and without specific learning disabilities (SLD). The Miami-Dade County Public Schools in Florida, which is the fourth largest system in the nation, was the district of study. The researchers focused on two urban middle schools, which each had a 94% Hispanic population and included 80 seventh or eighth grade participants from each school. In each school, 20 students were chosen for four subgroups: SLD in inclusive setting, SLD in segregated setting, non-SLD in inclusive setting, and non-SLD in segregated setting. The groups were matched with similar socio-economic levels, school attendance, and first language spoken and all had been in their specific setting for at least two consecutive years (Barracos et al., 2014).

The Barracos et al. study (2014) relied on the Florida Comprehensive Assessment Test (FCAT) to measure achievement in math and reading. The FCAT reports scaled scores each year as well as a development score, which shares an individual's growth over time and was the focus of this study. The researchers found no significant differences in achievement between any subgroup and determined that inclusion did not increase or decrease achievement for SLD. They concluded that “if students can achieve equally in a segregated or inclusive setting, certainly students should be included by default” (p. 8). They suggested that the district focus more heavily on training provided for teachers working in inclusive classrooms to help them know how to differentiate for all learners and implement more effective interventions (Barracos et al., 2014).

While these two studies merely showed that including students in the general education co-taught classrooms does not decrease learning, studies that have more of a longitudinal focus would be beneficial for further research (Cramer, 2015, Barracos et al., 2014). The push towards inclusion helps students access the general education curriculum more easily and helps them feel included with their non-disabled peers. More focus on teacher training in inclusive settings and increasing knowledge of the predictors, indicators, and effective strategies for individual students’ specific learning needs will hopefully raise those achievement levels in the future.

Effective Strategies

While the studies above give teachers ideas of how to accommodate students with dyscalculia based on the major predictors and indicators of the disorder, the following studies show data based on specific interventions. These studies take place in the elementary and secondary levels, but could very well work across settings. Teachers can use these ideas or variations of their own choosing to adapt their instructional strategies and routines.

Elementary

One very recent study showed that an effective strategy for preventing developmental dyscalculia (DD) in early learning could be adding an intensive abacus course (Lu et al., 2021). An abacus is a manual calculator in which students can use beads to show different numbers and operations. The quantitative study was a tier 1 intervention, meaning that it was used for the general student population rather than specifically with students who were struggling in math already. Their goal was to begin the abacus course before students would typically start being identified as DD. Participants included 479 students in 12 first grade classrooms from schools in Jiangsu Province in China. There were six classrooms, which were in the experimental group and six in the control group. Parents of the participants signed informed consent (Lu et al., 2021).

For the abacus classes, students were given abacus training from a unified textbook for about 100 minutes per week, while the control group received non-abacus math training in the Lu et al. study (2021). The teachers were trained in teaching abacus and mental abacus math. At the end of the two year study, the students all completed eight computerized tasks including processing speed, non-symbolic number sense, spatial ability, short-term memory, attention, IQ, arithmetic ability, and language ability. The researchers determined that a student would qualify as DD if their arithmetic computation score was lower than the 7th percentile and the IQ score was above the 25th percentile. Results showed that the average DD rate in the abacus classes was zero, while the control group averaged 6.4% DD rate. They concluded that a long term abacus course could prevent developmental dyscalculia from occurring (Lu et al., 2021). Future studies could look at whether other math manipulatives could also be as beneficial as the abacus.

To tackle the idea of a visual perception deficit, Cheng et al. performed an eight day numerosity training for students with developmental dyscalculia (DD) in 2020. They hypothesized that the training would improve student's scores in symbolic arithmetic and approximate number system (ANS) acuity. They found participants who were third to fifth grade students from four different primary schools in Beijing. The students met the criteria for dyscalculia if their arithmetic skills were lower than the 7th percentile and their IQ was above the 25th percentile. Eighty participants were chosen and randomly split into two training conditions, one with the numerosity training and one with English dictation training (Cheng et al., 2020).

The training involved in the Cheng et al. study (2020) focused on "...training the mental representation of numerosities, the relationship among numerosities, and their relationship with numerical symbols" (p. 3). The researchers measured the individuals' figure matching, numerosity comparison, simple subtraction, sentence completion, and mental rotation before and after the intervention for both groups. They found that the intervention group had a significant increase in the areas of arithmetic performance, visual form perception, and ANS acuity and concluded that "non-symbolic numerosity training could improve arithmetic fluency in children with DD, and visual form perception is the underlying cognitive mechanism in the training effect" (p. 6). They are interested to see what a longer course could do to improve the benefits for these children (Cheng et al., 2020).

The next study (Kaufmann et al., 2003) for elementary learners sought to increase the basic numerical and conceptual knowledge in students with MLD with a numeracy intervention program. This quantitative study included participants in the intervention group, which included six individuals with developmental dyscalculia and 18 individuals for the control group who did not. All participants were in third grade and right handed. The school psychologist confirmed that the students with developmental dyscalculia had significant discrepancies between their intelligence and arithmetic scores. The groups were given an individual calculation battery before and after the experiment to assess gains during the intervention (Kaufmann et al., 2003).

Kaufmann et al. (2003) specifically designed the intervention to focus on moving from concrete to abstract numerical knowledge, modifying materials to have a few recurring skills, incorporating many games, and "...explicit teaching of conceptual knowledge in every single module" (p. 566). The outcomes of their experiment showed that the intervention group had significant increases while the control group did increase, but not significantly. The researchers took a special interest in the increases made in the experimental group in comparison to the control group for the areas of arithmetic fact, procedural, and conceptual knowledge. They concluded that the positive effects were mostly due to the focus on the explicit numeracy teaching employed in the intervention program (Kaufmann et al., 2003).

In 2012, Zhang et al. hypothesized that using visual chunking representation (VCR) to accommodate tests for geometry students would help students with math learning disabilities increase their test scores. The researchers were concerned about overloading the students' visual working memory. The participants for this quantitative case study included four students with low math scores from an elementary school in the Midwest. All four students scored an average or above average score on an IQ test, but scored below the 35th percentile on the Woodcock Johnson Test of Achievement for math fluency. Each student had been previously taught a geometry unit, but the instruction was not a part of this study design (Zhang et al., 2012).

The testing probes given in the Zhang et al. study (2012) had two conditions: a standard testing condition with traditional representation and a VCR testing condition with shading applied to help students see the shapes involved. The geometry problems were selected from curriculum supplementary materials to prepare for the Florida Comprehensive Assessment Test (FCAT). The tasks "...asked students to imagine manipulating (e.g., folding, sliding, turning) a shape and to choose the new shape that could be formed" (p. 171). Since the two conditions were the same problems with and without the applied VCR accommodation, the students were given the test with a different order of test questions to ensure validity. The researchers concluded that their hypothesis was correct and the students with math disabilities performed significantly better on the test questions with VCR accommodations compared to the standard test questions. A survey of the students further supported their conclusion because the students shared they felt the VCR conditioned questions were easier (Zhang et al., 2012).

The studies conducted at the elementary level included three instructional practices (Lu et al., 2021; Cheng et al., 2020; Kaufmann et al., 2003) and one accommodated assessment theory (Zhang et al., 2012). Lu et al. (2021) showed that an abacus class decreased how many students were later assessed to have developmental dyscalculia. Although not specifically, this suggests that physical manipulatives could be very beneficial for students with math learning disabilities. Cheng et al. (2020) found that a numerosity training focused on increasing the visual perception increased math scores in students while Kaufmann et al. (2003) found success with a numeracy intervention program which explicitly taught basic numerical and conceptual knowledge in students with MLD. Finally, Zhang et al. (2012) showed that by simply structuring geometry tests so the shapes are clearly discernible, students' scores increase without any specific supplemental instruction.

Secondary

The secondary school study by Gonsalves et al. (2014) hypothesized that by using number line instruction, students could solve math word problems with more accuracy. The researchers carried out a case study of 10 sixth grade students. One student, named Maria, was focused on with more detail. The students were drawn from an unknown school in an unknown area, but they all qualified for special education with a learning disability. The researchers asserted that "Most students, especially those with LD, do not benefit from such general prompts and need to be explicitly taught how to reconstruct the problem information in a number line format" (p.162). The students were given private remedial instruction three times a week for about 35 minutes per session using number line approaches and their progress was measured (Gonsalves et al., 2014).

The full intervention in this Gonsalves et al. (2014) study included "...instruction on reading, paraphrasing, visualizing, hypothesizing, estimating, computing, and checking" (p. 166). The trained research assistant began with the first concept and did not move on until the individual earned 75% on three of four skill based measurements. The highlighted progress of Maria showed she had steady progress beginning after the first training session, reached mastery after five sessions, and it was maintained for two months. The researchers did share that she lost her progress four months after training had ended and concluded that instructional maintenance could have helped. They acknowledged that number lines do not always fit every word problem, but insisted that helping students with learning disabilities conceptualize the word problems in an organized structure helped them gain success with the difficult skill of mastering word problems (Gonsalves et al., 2014).

The instructional method tested by Herr et al. in 2018 was an interest-based method versus traditional method for teaching math word problems and the effects on students with and without learning disabilities (LD). The quantitative study focused on 41 seventh grade students from two classes who had been randomly assigned to those classes. The intervention class and the control class were both inclusive classrooms, which each had around 20% of the students with special education services. Signed written informed consent of parents or guardians was obtained by the researchers (Herr et al., 2018).

Herr et al. discerned which individual interests the students had by giving them a survey once they had finished their math word problem pretest. Those interests were used to rewrite word problems in the interest based curriculum. The teacher for the intervention group was given training on how to rewrite word problems based on student interest, but was told not to change other teaching methods during the four week intervention. The post-tests given were identical to each other, but were written with the interests of the intervention group in mind. The researchers reported that although there was no significant difference between the LD groups for the pre-test, the intervention group of students with LD scored significantly higher on the post-test. They saw no significant increase in the students without LD. They concluded that interest based training increased posttest scores for students with LD possibly because they had an easier time perceiving or visualizing what was happening in the problems (Herr et al., 2018).

These two secondary studies both focused on instructional supports for math word problems (Gonsalves et al., 2014; Herr et al., 2018). The first found that explicit instruction using number lines was an effective tool, which helped students make a visual plan before they found the correct answers (Gonsalves et al., 2014). The instructional strategy by Herr et al. (2018) used an interest-based approach, which they found helped students with learning disabilities increase their test scores.

CHAPTER III: APPLICATION OF RESEARCH

The following application of research has been developed with the most updated version of Core Connections Algebra (CCA), which is one course of the CPM Educational Program Curriculum (Dietiker et al., 2022). This curriculum was adopted by Richfield Public Schools (MN, United States) in 2018 and is used for grades 6 through 12. CCA is the foundational course at Richfield High School as a majority of the ninth grade students take the course. There are also older students who are enrolled in the course due to failing it previously or pushing up from a special education resource class, which focuses on pre-algebra skills.

The CCA curriculum has eleven chapters and an appendix chapter, which can be utilized after the first chapter to reinforce the foundational concepts needed to solve and evaluate with variables. Teaching this optional chapter helps get all students on the same page and helps them build conceptual understanding with the manipulatives named algebra tiles, which is especially helpful for students with specific learning disabilities in math (SLDM). The algebra tiles are helpful in future chapters as well, especially when multiplying polynomials and factoring polynomials. The Appendix chapter of the CCA curriculum was chosen for this project because it already is very effective in helping students learn how to solve for a variable, but it is also primed for some extra supports that, if embedded well, can harmonize with the curriculum to help students with SLDM find early success with the curriculum.

This application walks through each lesson and highlights possible instructional supports that can be embedded by the special education teacher or math teacher. This application also includes a list of accommodations that would be beneficial for many students with SLDM. In order to provide an organized system for the students, teachers provide a color coded binder system with dividers that they slowly build throughout the year. Each chapter will maintain the same color throughout except for the especially important papers, which will be color coded gold. The gold sheet of the chapter will be commonly referred to by the teachers as they encourage their students to keep it out in order to easily access as well as be available to add new ideas. Oftentimes the gold sheets will be the important vocabulary from the chapter but it will also include formulas and procedural steps for concepts. One assessment accommodation for students with SLDM will be to have access to the gold sheet during their test.

The following CPM content is meant for use in the Richfield Public Schools, who have permission to use the CPM curriculum and are prohibited from use outside of districts who partner with CPM. This researcher obtained permission from CPM to use their materials for the purpose of this application emphasis for this research paper.

Appendix A ~ Chapter Outline - Core Connections Algebra (CCA)

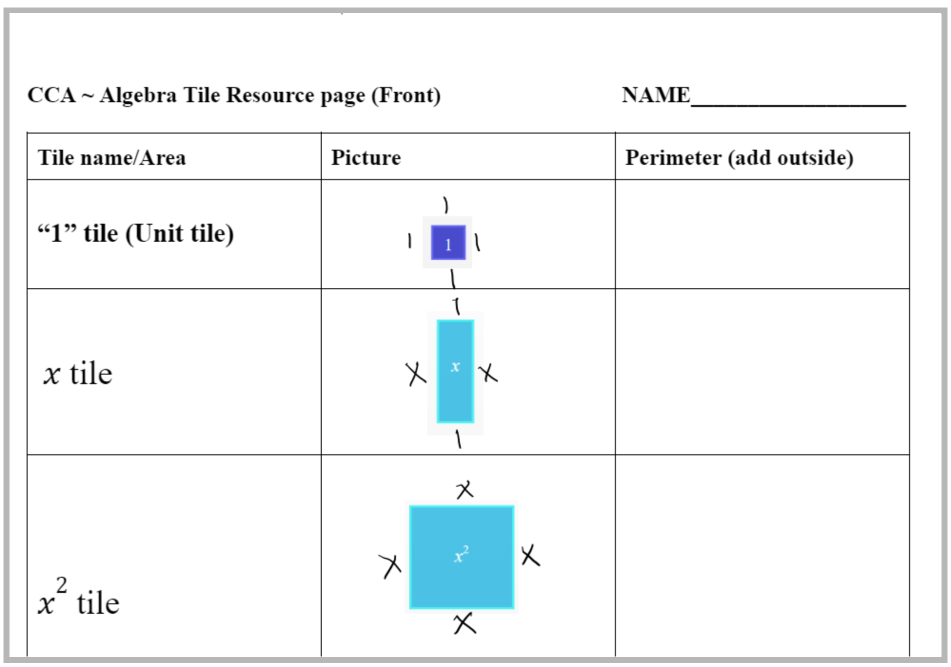
A.1.1 ~ What is a Variable?

In this first lesson, students will explore unknown numbers called variables by being introduced to algebra tile manipulatives. The tiles can be accessed online through the curriculum or by using the actual pieces, which have been obtained by Richfield High School. These tiles are named by their areas and help students see the difference between x, x^2, y, y^2, and standalone numbers. The lesson itself is already very effective and it lets students discover and get curious about how the tiles and concepts relate to each other. This lesson hints at the idea of combining like terms by simply counting how many of each tile they have, but not explicitly teaching it yet. They will start to see a connection between a written mathematical expression and the tiles that represent it. Practice with the physical manipulatives is helpful for students with SLDM to start being able to visualize what is happening with the written form.

Besides the collaborative team activities, which will help all students as well as the manipulatives, which help build conceptual understanding, some specific supports for SLDM students include a check in with either individual teams or the whole class to ensure the explicit understanding of how one written expression is shown with the tiles and writing out the tile names, students drawing out pictures on their gold sheet (which can be utilized for their tests) as can be partially viewed in Figure 1 and on the back in Figure 2 to start filling in their understanding of vocabulary.

Figure 1

Front of Gold Sheet Resource Page



CCA ~ Algebra Tile Resource page (Front) NAME__________________

Tile name/Area	Picture	Perimeter (add outside)
"1" tile (Unit tile)		
x tile		
x^2 tile		

Figure 2

Back of Gold Sheet Resource Page

CCA ~ Appendix Vocabulary Sheet (back) **NAME**____________________

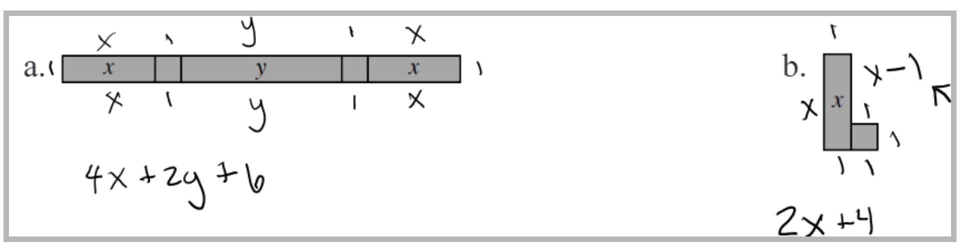
Vocabulary Term	**Definition**	**Picture/example**
Variable	a letter that represents a number	x, y, m, b

A.1.2 ~ What is Perimeter?

The next lesson continues to explore the algebra tiles and how they can be used to help simplify expressions. The idea of perimeter will also be examined. This lesson will continue to benefit students in picturing the math conceptually by letting them physically move the tiles. In Figure 3, students will find the perimeter of the figure and combine like terms. As you can see on the right, it can get quite tricky when some parts are covered up. It will be important to let the students struggle together for a time, but then check in on specific groups to make sure there is an explicit understanding of why one side includes subtraction or a negative.

Figure 3

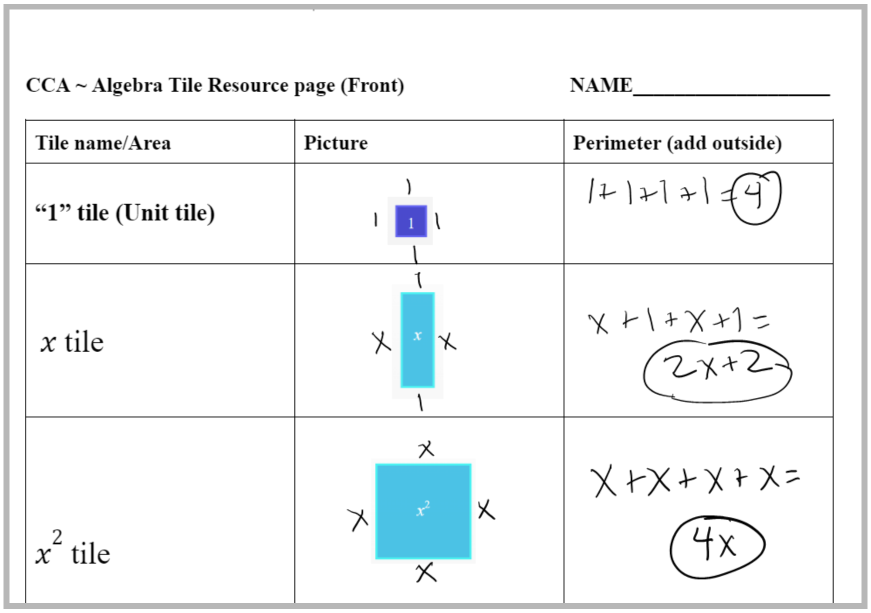
Two Perimeter Problems with Algebra Tiles



To close the lesson, the students will refer back to their gold sheet and complete the perimeter column as seen in Figure 4. It is important for the teachers to check that correct answers are included in the column. This will help anchor the area versus perimeter tasks for students with SLDM.

Figure 4

Gold Sheet with Perimeter Column Completed



CCA ~ Algebra Tile Resource page (Front) NAME__________________

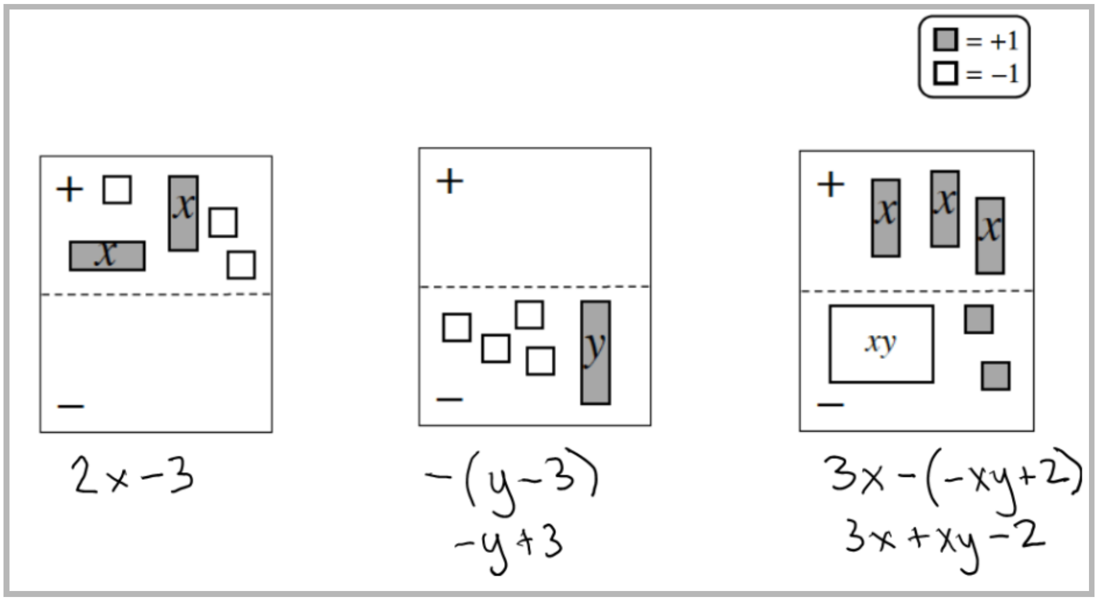
Tile name/Area	Picture	Perimeter (add outside)
"1" tile (Unit tile)		1+1+1+1=4
x tile		x+1+x+1= 2x+2
x^2 tile		x+x+x+x= 4x

A.1.3 ~ What does "Minus" Mean?

This lesson will introduce the red side of the algebra tiles, which will be known as the negative side. Students will also be introduced to the expression mat, which is a physical mat that students can use with the algebra tiles. It has a positive and negative region as seen in Figure 5. This mat helps students see that -(-1) = 1. To help SLDM students not get lost, this lesson will get narrowed to practice pairs instead of groups and four so students will always be occupied with math work. While one student moves tiles from region to region, the other will write the algebraic written form of what is happening, working to simplify the expression as much as possible. Students will be encouraged that it can be written in different ways, but if they know they get confused with negatives, they can use the method as shown in Figure 5 with the parentheses.

Figure 5

Three Examples of Simplifying on an Expression Mat



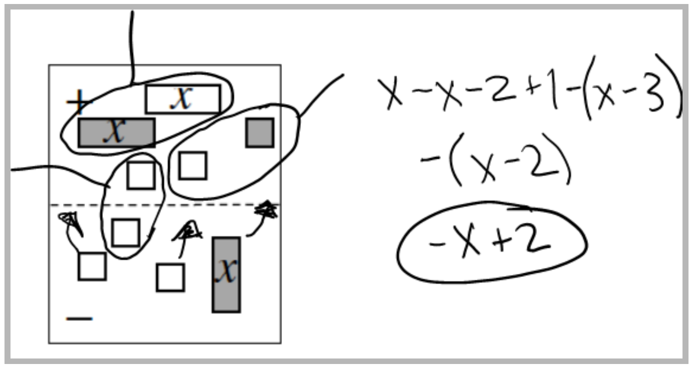
To close, students will fill in the back side of their gold sheet with the vocabulary words expression, term, and combining like terms. This is also a great lesson to do a check-in by giving an exit slip, a quick comprehension check. No points will be given, but the teachers can check in with students who need extra help the next day during a warm up.

A.1.4 ~ What Makes Zero?

Lesson four focuses on using the idea of making zeros to simplify algebraic expressions. Again, the expression mat and algebra tiles are used so students can connect the written to the conceptual skills and connect to previous lessons. Students will experiment with the different ways to show how the tiles can simplify to zero. This is an opportunity to show students that subtraction can also be shown as adding a negative number, which can be a confusing concept. As additional proof for students with SLDM, they can check on their calculators to ensure that the answer becomes zero. Still working in pairs for this lesson, the students benefit from having a graphic organizer in addition to the expression mat and tiles to help them organize what is happening algebraically.

Figure 6

Example of Making Zeros



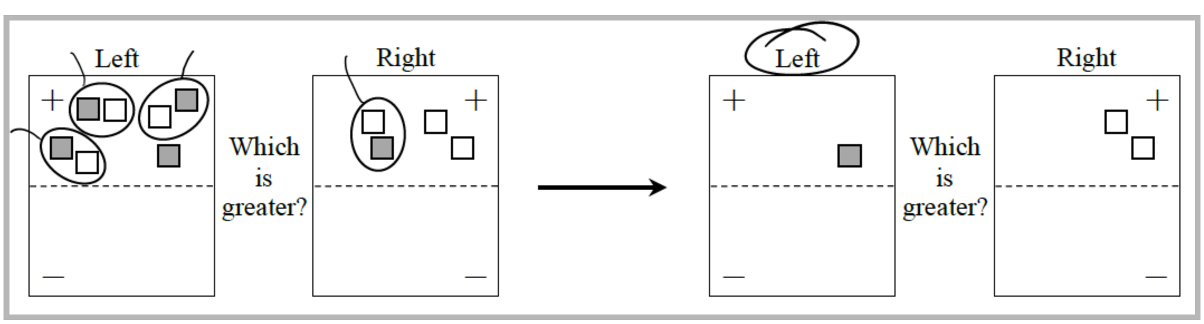
To close, the students can write down some of the "legal moves" they can do to simplify expressions on the vocabulary side of their gold sheet.

A.1.5 ~ How Can I Simplify the Expression?

This fifth lesson of the appendix chapter continues to let students practice simplifying algebraic expressions, but adds in the idea of comparing two simplified expressions. Tools used in this lesson include the algebra tiles and an expression comparison mat, which is similar to the expression mat, but has two expression mat visuals on one paper. Again working in pairs instead of groups of four, students will use previously learned strategies to simplify expressions, taking turns with who is moving the tiles as seen in Figure 7 and who is recording steps in an added graphic organizer which is shown in Figure 8.

Figure 7

Example of Simplifying with a Comparison Mat



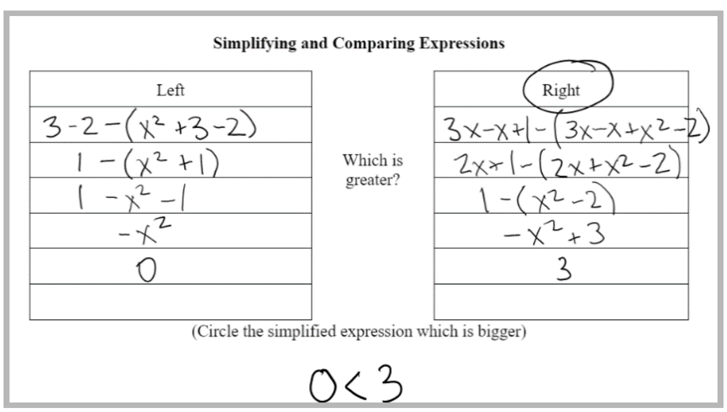
This lesson will include writing out simple inequalities which can have some obstacles for students with SLDM. First, the inequality symbols < and > are easy to mix up, so having a large visual representation on the board would be helpful for students including adding the symbols to their gold sheets. Another tricky aspect is comparing negative numbers. A way to bring in an interest-based subject is to compare negative numbers to owing someone money. If a student is having trouble with the concept, the teacher could ask, “Would you rather owe your friend two dollars or three dollars?”

A.1.6 ~ Which is Greater?

Lesson six incorporates more practice with simplifying and comparing expressions, but increases the difficulty level. Continuing in pairs, students will try to simplify complicated expressions and write out the steps along the way as seen in Figure 8.

Figure 8

Graphic Organizers for Comparing Expressions in Written Form



After they have gotten some good practice in, the teams of four will receive a white board and will compete against the other groups in the classroom as a fun way to catch common errors that may still be happening. Each team member will get a chance to write out the simplified inequalities, but their team members can help discuss their final answer.

A.1.7 ~ How can I Write it?

In this lesson, there is a lot of practice from previous lessons as well as adding in the justifications or explanations of which legal moves were made. For the first part of the lesson, students will practice simplifying expressions and comparing the final expressions using an inequality symbol and graphic organizer as seen in Figure 9.

Figure 9

Graphic Organizer including Written Explanations

Left Expression	Right Expression	Explanation
$3x + 4 - x - (-2) + x^2$	$-1 + x^2 + 4x - (4 + 2x)$	Original expressions
$3x + 4 - x - (-2)$	$-1 + 4x - (4 + 2x)$	remove x^2
$3x + 4 - x + 2$	$-1 + 4x - 4 - 2x$	flip to positive region
$2x + 6$	$2x - 5$	combine like terms
6	-5	remove $2x$
Because $6 > -5$, the left side is greater.		

This is helping students get ready to solve for x, or any single variable equation, because it is helping them see that they must remove equal pieces from each side. It also helps them prepare for two column proofs, which they will see in the geometry curriculum the following year. After this practice with justification, students will practice a fun and challenging activity on a large group white board. The students will each be given an expression or a picture of tiles with a perimeter to find. They will first find their own simplified expression, then as a group they will combine their expressions to see if they combine to the given answer in the middle. This activity helps students move their short term working memory into long term memory.

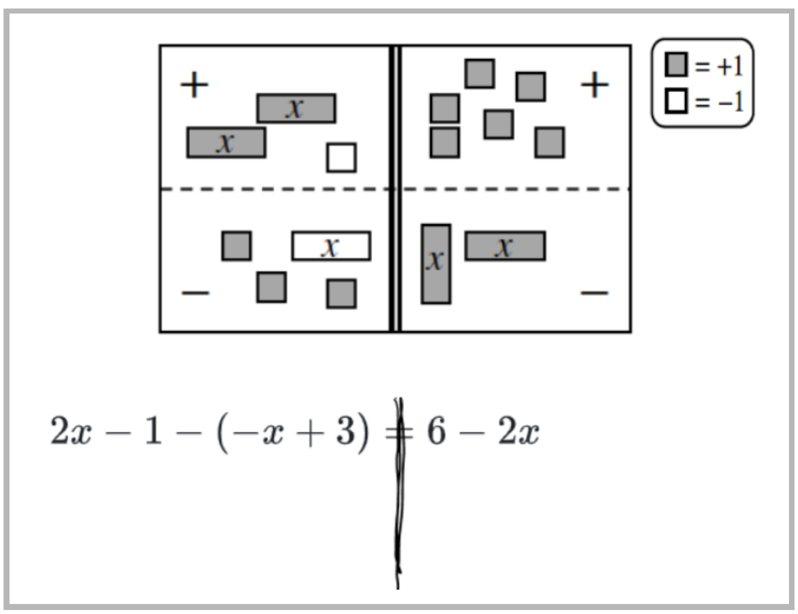
To close, the students will take a formative individual assessment to assess progress and identify students who need more help. All students can use any of the manipulatives and any notes to help them.

A.1.8 ~ What if Both Sides are Equal?

In lesson 8, groups start moving from comparing expressions to solving equations. They will quickly see the similarities between the two, especially as the expression comparison mat gets switched out with the equation mat, which is very similar. This is another lesson that would highly benefit students with SLDM if they work in pairs instead of groups of four and get explicit understanding check-ins to make sure they understand the legal moves that can be made and how that looks in written form. The teachers can use the online tool available through CPM to model what one partner does with the tiles while the other writes down the steps and the language they use to communicate.

Figure 10

Solving for x on Equation Mat and in Written Form



To close, the students will try checking their work by replacing each x tile with the number of tiles they think it equals in the original equation. If the two sides of the equation are equal in value, they can be sure that their answer is a correct solution.

A.1.9 ~ What is x?

Lesson 9 is the second solving lesson and will help students feel a little more confident in their solving skills. After a warm up, which helps reengage their ideas for how to solve, the students will write down their ideas on their gold sheet about the common step order needed to solve for x including combining like terms on each side, getting x tiles one side, getting unit tiles to opposite side, and dividing both sides by how many x tiles there are to see the value of one x tile. Having it written down as a reference tool will help students with SLDM when they are stuck. Students will then continue practicing in pairs to solve problems given to them in picture form and then written form. They can choose to use the tiles at any point, but are given permission to switch to written form to see if they can visualize what they need to do without the tiles. They will continue to check their work, but this time in written form instead of the physical tiles.

To close, the students will be shown two side by side solving techniques with a common error for one of them. As a team they will need to decide who made the mistake and what the mistake was.

Closure ~ What have I Learned?

In the closure lesson, the students will begin with a fun activity similar to the one utilized in lesson 7 with the big white board. This activity is called the sum activity and students will each get their own solving problem and the group sum. Once they each get their own answer, they will combine their answers to see if it adds up to the sum. After they get the correct answer, they get a new set of problems at a slightly higher difficulty level. Together, they can help each other solidify their math knowledge and procedural steps for solving.

The final assessment for the chapter is a formative team test rather than a summative test since the skills taught are not technically at the ninth grade standard. Each individual will get their own test with similar but different questions on it. They can use each other, their notes, the algebra tiles, and mats to write down their steps and find their final answers.

Accommodations

The following accommodations are recommended based on the literature above for students who have a learning disability in math. Each student will likely have more based on individual characteristics and possible comorbidities such as a learning disability in reading or writing, Autism, or Attention Deficit Hyperactive disorder (ADHD).

- Visual and verbal directions, repeated and clarified
- Graphic Organizers
- Color coded organizing system provided (Binders with dividers recommended)
- Skills that will be assessed given ample repetition and practice
- Examples of end product
- Extra time for assignments and assessments or modified length
- Formula sheet with vocabulary and procedural steps for assessments
- Access to calculator and printed multiplication tables

CHAPTER IV: DISCUSSION AND CONCLUSION

Summary of the Literature

The case studies and experiments found for this paper were extremely helpful in giving a great overview of dyscalculia starting with predictors and indicators, then common comorbidities and their effects, and ending with settings and effective strategies. Each section worked with the whole and supported an important aspect of the literature that helped give myself and therefore other teachers a better understanding of dyscalculia, what it is and how to help students who potentially have it.

The predictors, or possible predispositions, of dyscalculia were unique and revealing. The four studies studied factors that could help predict if an individual would end up having dyscalculia and a math learning disability. To start, Mammarella et al. (2021) indicated core deficits in their cognitive functions were not predictive of math learning disabilities (MLD), which suggested if someone has a low IQ that is not a predictor of dyscalculia. While low intellectual scores do not predispose a person to have dyscalculia, a different study concluded that preterm birth could (Adrian et al., 2020). Another study (Kuhl et al., 2021) went deep into children's minds, almost literally, and found that they could see differences in childrens' frontoparietal network in their brain using an MRI, which could predict if a student would struggle with math far before they could be tested with actual math tasks. Finally, Shalev et al. (2001) found that dyscalculia is likely genetic due to a significant familial prevalence of the disorder. These predispositions help to paint the picture of why individuals with dyscalculia have these specific differences.

Going beyond predictors, it is important to understand the main underlying indicators of dyscalculia. Three studies highlighted important aspects that will likely be prevalent in those with MLD or dyscalculia and a couple others from the next section of comorbidities also lent valuable information. First, Cheng et al. (2018) concluded that visual perception deficits were an underlying contributor in dyscalculia, which makes it difficult for students to take in the same information from visuals. Next, Mazzocco et al. (2011) determined that the Approximate Number System (ANS) including magnitude, comparing amounts, and estimating numerical distance was an indicator of dyscalculia. Morsanyi et al. (2018) agreed with the others, but found that an order processing was the strongest indicator yet, which was further supported by a study that found an order processing deficit in those with dyscalculia and dyslexia (Hachmann et al., 2014). Finally, another study (Rubinstein et al., 2006), which focused on dyslexia in addition to dyscalculia, found that both disorders had significantly slower reaction times in automatically recognizing symbols; phonological symbols showed slower reaction times for those with dyslexia while numerical symbols were slower for those with dyscalculia. Beyond struggling generally with math, these indicators give a better understanding of which aspects of math are the biggest obstacles.

As seen above, there are many links between dyslexia, which indicates students struggle in reading, and dyscalculia, but attention deficit hyperactive disorder (ADHD) and math anxiety may also affect dyscalculia. In addition to the studies above, Peters et al. (2018) turned back to the brain and established that there are similarities between the brain activity with those who have both disorders. In fact, Shalev et al. (1997) found that individuals with developmental dyscalculia and a comorbidity of a reading disability showed a significant reduction of an individuals' math scores than compared with those with a math disability only or with those with a comorbidity of ADHD. The last comorbidity studied was math anxiety, but Devine et al. (2018) concluded that although many students with dyscalculia had math anxiety, they found it is not a predictor of math scores. The studies of Hachmann et al. (2014), Rubinstein et al. (2006), Peters et al. (2018), and Shalev et al. (1997) showed that dyslexia has the strongest correlation with dyscalculia.

The idea of a least restrictive environment was also explored. In special education, the student's team is supposed to keep students with their non-disabled peers and in the general education setting to the greatest extent possible. Two studies showed that including students in the general education co-taught classrooms did not decrease learning and that the math scores were similar to those in the resource setting, which is a small group setting with special education students only (Cramer, 2015, Barracos et al., 2014). Hopefully, with better teacher training for a co-taught setting and greater knowledge of the predictors, indicators, and effective strategies for those with dyscalculia, future research will find better outcomes for students in inclusive, co-taught settings.

Studies that focused on interventions were the final part of the research included in this paper. Studies conducted at the elementary level included interventions for three instructional practices (Cheng et al., 2020; Kaufmann et al., 2003; Lu et al., 2021) and one focused on making accommodations on tests (Zhang et al., 2012). Lu et al. (2021) showed that an early abacus class not only decreased how many students were later assessed to have developmental dyscalculia, but could potentially bring that number to zero, which is significant. Cheng et al. (2020) concluded that an intervention of visual perception numerosity training increased math scores in elementary students and Kaufmann et al. (2003) also found success in an intervention, which explicitly taught basic numerical and conceptual knowledge in students with MLD. In the testing accommodation study, Zhang et al. (2012) showed that by changing geometry problems so the shapes are more clearly discernible with a specific shading technique, the third grade students found it easier and they scored higher on their tests. Even though the interventions were for elementary aged students, similar strategies could be applied to secondary level instruction and assessments.

For the secondary level, two instructional strategies for math word problems were included (Gonsalves et al., 2014; Herr et al., 2018). Gonsalves et al. (2014) taught students to use number lines as a tool to help them visualize what was happening and concluded it helped students reach mastery. Herr et al. (2018) focused on an interest-based approach, which helped students with learning disabilities stay engaged during lessons and also increased their test scores. Word problems can be tricky for many students, so both of these interventions are helpful when developing instructional techniques.

Limitations of the Research

Resources for this thesis were gathered mostly through the Bethel University Reference Library using the databases available to me. When I first began my research, I began using the Academic Search Premier database and I simply searched for “discalculia” (misspelled on purpose). I was able to find some helpful sources, but it took me a few days to realize I had misspelled the topic of my research. Please note, this was after I had added the misspelled word to my word document’s dictionary so it would recognize it as correct. Once the error was found, I began searching for “dyscalculia” spelled correctly in the same database and began adding in such as “and math disability”, “and team teaching”, “and co-teaching”. There were a good amount of results and no narrowing down of the search was needed.

Next, the ERIC database was used as it focused on education. Again, keywords used for searches included singular and combinations of the following words: “dyscalculia”, “math disability”, “secondary”, “interventions”, “team teaching”, “co-teaching”, “co-taught classes”, “least restrictive environment”, “instruction”, “accommodations”, “modifications”, “algebra”, “learning disability”, “comorbidities”, and “dyslexia”. All searches were narrowed down to articles which were peer reviewed, had the full text available, and were found during June and July of 2022. Search parameters included journal articles written between 1997 and 2021, but those parameters were due to the topic of dyscalculia being fairly recent in nature, rather than the narrowing the window of time.

International studies from around the world were used including North America, Europe, Asia, and the Middle East. It was noted how individuals all over the world could struggle with math no matter their background and first language. Since dyscalculia is a disorder, which commonly persists throughout one’s life, studies with participants whose ages ranged from birth through college age were included in this research.

Implications of Future Research

As one can see from the dates of most of these studies, the topic of dyscalculia has been studied more broadly within the past five years than previously. Although this is encouraging, it suggests that there are many more studies that can and should be done. On July 6th, 2022, I searched for peer reviewed articles in the ERIC database for dyscalculia and 61 results were received; then, using the same parameters, but with dyslexia in its place, there were 1,357 results. Clearly, there is more research to be done for the benefit of those who have dyscalculia or those around them such as teachers who wish to help them become better mathematicians.

More studies need to be conducted with high school students, especially in the team taught setting. There were no applicable studies that focused on that specific level and setting. There are many students who struggle more in math once unknowns or variables are introduced, which is very frustrating for them. Finding more empirical research on interventions specifically for high school would benefit not just me, but many high school teachers.

Most specifically, I would love to see research done using algebra tiles or similar math manipulatives and the effects it has on students with a learning disability in math. I have seen the algebra tiles greatly benefit my students, but I would love to see an unbiased study done to measure how effective the tiles are. This could be utilized for middle school students as well as high school students, perhaps even as a longitudinal study for students with math disabilities.

Professional Application

The things I learned from this project will stick with me for the rest of my career. Being more “math-brained”, I have always tried to avoid academic writing. Despite this, research projects have always taught me so much. This project was incredibly helpful for me to learn more about why I have been seeing specific struggles in many of my students, and now how I can have a more broad understanding of what is difficult for them and how I can best help them learn. Before, I was using trial and error to come up with strategies that may or may not work. Now, I will be able to tweak lessons, visuals, accommodations, and activities to help students access the general education curriculum.

As seen in the application emphasis of this thesis, the research I did helped me design an accommodated version of a specific chapter from the math curriculum we utilize at Richfield High School as well as develop some key accommodations to be added to students’ Individualized Education Program (IEP). For the chapter, I focused on including high interest activities that would keep students engaged, math manipulatives for most lessons, graphic organizers, and checks for explicit understanding instead of assuming that the students understand the content. The curriculum itself is already very good at helping students build conceptual understanding for the skills and tasks that are asked of them.

An organizational tool my co-teacher and I have already implemented and will continue to use is a color coded binder system, which helps students keep track of their math learning. This has been an effective tool already and researching dyscalculia helps me understand why that is. The binder system includes a new colored paper for each chapter and "gold sheets", which are to be seen as the most valuable and can be available as a supplementary tool during a test for those with a math disability. The gold sheets often include vocabulary, formulas, and procedural steps to help students not get lost in the processes we ask them to do.

I have been team teaching in math since 2015, and see myself as a part of the math department in addition to the special education department. When I make tests in an accommodated version or a modified version, I often share it with other teachers in the department who have students who need it. When the new curriculum was implemented, I was able to do the training alongside my colleagues. We have planned together, shared our struggles and successes, and have shared our best ideas. I am proud to share my ideas with my colleagues and suggest specific instructional techniques that would benefit students with disabilities in their classrooms. I am truly excited to share many of these new ideas that I have gained as a result of this research.

A new partnership I would like to build in my building is with the science department. This has been an idea I have had for a time, but now I am even more certain I would like to build a bridge between the departments, especially with the chemistry teachers. If similar math supports are used between the two departments, it will help students access their previous knowledge more easily. My goal is to make sure everything has been done to help students feel successful in their learning, despite any learning differences they have.

Another department I would like to continue to bring my ideas to is the special education department. The hope is to bring similar lists of suggested accommodations to the team for students with learning disabilities in reading, writing as well as students with other disabilities. Accommodations should always be individualized to each individual student, but having a list of helpful accommodations depending on their disability label would be a great tool to have.

Finally, I am excited to continue to share my ideas as a part of our building instructional leadership team (BILT). I will be able to voice concerns and suggestions over instructional decisions that may affect students with specific needs, like dyscalculia. There will also be opportunities for me to be involved in teacher training where I can help teachers across the building learn about students with learning disabilities and how they could benefit from specific accommodations and interventions.

Conclusion

The guiding research question for this thesis was: How can general and special education teachers effectively support students with dyscalculia?

In conclusion, general and special education teachers can build in specific accommodations, visual examples that are always accessible and easy to understand, graphic organizers and systems that are easy to use, interest-based activities and lessons that are interesting and challenging, math manipulatives, which help the students conceptualize the problems, and checks for explicit understanding to ensure learning continues. All of these things will be beneficial for students with dyscalculia, but just as their learning continues, so should the learning of teachers. We need to continue to learn about the disabilities of those we teach and keep making our classrooms a place where they can find success. That way, as adults, instead of sharing a dislike of math, they can say, “Math was difficult for me at times, but I enjoyed the challenge”.

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