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Supporting Working Memory Development in Schools During Adolescence

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Abstract

This master's project investigates the multifaceted aspects of working memory in secondary school students and its relationship with academic performance. The findings from this project contribute to the existing literature by offering insights into the effectiveness of holistic interventions and memory strategies in enhancing working memory abilities and optimizing academic outcomes in secondary school students. This project reviews evidence about the relationship between emotional regulation, stress, and working memory to understand better how emotional factors impact cognitive functioning in the classroom setting. This analysis also aims to shed light on the trajectory of working memory development during adolescence and its potential implications for academic performance. The outcomes of this research have practical implications for educators, administrators, and policymakers working with secondary school students with working memory difficulties. The knowledge gained from this research can inform the design and implementation of targeted and universal interventions that enhance working memory and support students' emotional regulation and stress management. Ultimately, this project strives to foster academic success and holistic well-being by recognizing the intricate interplay between working memory, cognitive development, stress, and academic performance in the secondary school context.

Keywords: adolescence, cognitive development, mindful practices, memory strategies, intervention implementation, stress, academic performance, secondary school students, working memory

Supporting Working Memory Development in Schools During Adolescence

Working memory is a fundamental cognitive process crucial to academic success and daily functioning (Ozimič, 2020). It involves temporarily storing and manipulating information and facilitating complex cognitive tasks such as problem-solving, comprehension, and learning. However, some students experience difficulties with working memory, which can significantly impact their educational outcomes and overall well-being (Ozimič, 2020). This project will assess the effectiveness of various approaches, such as memory training programs, cognitive strategies, and environmental adaptations, to determine their impact on improving working memory and enhancing academic performance. Additionally, the project will explore the role of emotional regulation, stress management, and the importance of a supportive classroom environment in supporting students with working memory difficulties. This research addresses how working memory uniquely contributes to learning during adolescence (10-19 years old) and how secondary schools can support the development of working memory skills universally and within individual classrooms. Ultimately, this master's project aims to inform educational practices and policy decisions by providing evidence-based recommendations and interventions to support working memory difficulties, promote inclusivity, and improve all students' academic outcomes.

Context

As educational institutions worldwide resumed in-person instruction following the Covid-19 pandemic, there has been a renewed emphasis on policies and protocols that address students' social and emotional well-being. Within this context, it is essential to recognize the interconnectedness of emotional regulation and working memory, two distinct cognitive processes that are mutually dependent. For instance, students who struggle with emotional regulation often experience limitations in engaging in executive functions such as working memory processes (Ozimič, 2020). Similarly, students with atypical executive function may exhibit difficulties in cognitive control over negative thought processes, leading to increased emotional dysregulation (Ozimič, 2020)**.**

Recognizing the significance of this relationship, federal policymakers have constructed guidelines for schools transitioning back to in-person instruction with the enactment of the American Rescue Plan (ARP). Through the Elementary and Secondary School Emergency Fund (ESSER), schools nationwide have been allocated significant funds, including $2,991,421,126 for Washington State (*Washington-State-ARP-ESSER-State-Plan-Approved-11-24-2021.Pdf,* n.d.). To access this funding, state educational agencies were required to submit reentry plans that implement research-based strategies addressing student mental health and well-being and identify the groups most impacted by the pandemic. Educational agencies have turned to organizations such as the Collaborative for Academic, Social, and Emotional Learning (CASEL) to address the need for evidence-based social and emotional strategies. Since its establishment in 1994, CASEL has provided rigorous peer-reviewed research on Social and Emotional Learning (SEL) programs. The cumulative research from CASEL demonstrates that mindfulness practices can benefit the parasympathetic nervous system, executive functioning, and emotional regulation.

In line with these efforts, the school district where my observational research was conducted has identified students living in poverty as the most vulnerable population. District analysts cited a 2019 community demographics study that found the percentage of youth living in poverty was 35% higher than rates across Washington State and 49% higher than the surrounding counties (*TPS Data - Tacoma Public Schools*, n.d.). The district's reentry plan utilized federal funding to implement the Character Strong Social and Emotional Learning program and to support teacher training on Whole Child Practices; the Character Strong program meets CASEL requirements by incorporating learning strategies that enhance cognitive processes like working memory, and the Whole Child professional development was suggested for teachers by federal policymakers (*Whole School, Whole Community, Whole Child (WSCC) | Healthy Schools | CDC*, 2023).

Importance

This research project is motivated by personal experiences growing up in rural Appalachia, which have provided firsthand evidence of the correlation between childhood poverty and an elevated risk of academic failure. Poverty can significantly diminish physical and emotional well-being and restrict economic and educational opportunities by causing constant stress in a student’s life. Given my background in a similar socio-economic context, I empathize with students navigating potentially disadvantaged environments while pursuing an education. As an educator, I recognize the limitations in alleviating the broader effects of poverty and the stress this causes a student; however, I believe that memory is an area where multidisciplinary strategies can be implemented to support students' cognitive development universally.

The global pandemic has subjected students to heightened psychological stress, yet it has also revealed their inherent strengths that can be harnessed within the classroom to foster resilient communities. Social and Emotional Learning (SEL) programs have emerged as valuable tools for mitigating the detrimental effects of poverty-related stress on learning and well-being.

Moreover, these programs have demonstrated the capacity to enhance cognitive control in executive functioning and emotional regulation, skills that have far-reaching implications beyond secondary school and should be considered when allocating educational resources.

Students who meet the criteria for specific disabilities are legally entitled to specialized educational services under the Individuals with Disabilities Act (IDEA). Working memory difficulties are prevalent among students receiving specialized education, with 10% of the general school population experiencing such challenges compared to 70% of students in specialized education programs (Wilson, 2017). Special education services follow a tiered system, encompassing universal classroom support (tier one), targeted interventions in small groups (tier two), and intensive interventions (tier three). Individualized Education Plans (IEPs) are commonly devised for students in specialized education, overseen by an education support team in alignment with a Response to Intervention Approach (RTI). Various medical, psychological, and developmental factors necessitate additional school support for students with working memory difficulties.

Purpose

The overarching objective of this research project is to understand the unique role of working memory in adolescent students aged 10-19 during the learning process. Specifically, this paper aims to investigate the efficacy of tiered support available to students with working memory impairments through the lens of universal SEL programs and targeted working memory interventions. Additionally, the project seeks to elucidate the interplay between emotional regulation and working memory processes. By examining the interrelationships between working memory, emotional regulation, and educational interventions, this research contributes to the existing knowledge on supporting students with working memory difficulties. The findings will inform educational practices, focusing on the effectiveness of tiered support models for working memory and the integration of SEL programs. Ultimately, the aim is to optimize educational outcomes for all students by fostering a comprehensive understanding of the interplay between working memory processes, cognitive development, stress, and effective instructional strategies.

Focal Questions:

1. How does working memory typically develop during adolescence?
2. What role does working memory play in learning during secondary school?
3. How does stress influence students' working memory capacities at school?
4. How can secondary schools support working memory development?

Literature Review

This literature review critically examines the existing research about the role of working memory in the context of secondary schools. British psychologist Alan Baddeley defines working memory as a cognitive system that facilitates the temporary storage and manipulation of information necessary for complex cognitive tasks such as language comprehension, learning, and reasoning (Baddeley, 2010). The development of comprehensive models of human working memory has enabled cognitive neuroscientists to investigate the neural mechanisms underlying this cognitive system and its constituent components, particularly about various aspects of learning within secondary school settings. This review outlines the foundational theory underpinning the conceptualization of human working memory to establish a foundation for scientific exploration in this domain.

Subsequently, the review examines research concerning the typical trajectory of working memory development during adolescence. This analysis aims to provide insights into secondary school students' normative patterns of working memory maturation. Next, this review explores the implications of working memory in educational contexts, encompassing its relevance across different subject areas and its impact on academic performance. The integration of empirical findings from various studies sheds light on the multifaceted nature of the interplay between working memory and academic achievement in secondary school students. Finally, this review synthesizes the current body of research regarding the effectiveness of various school-based supports targeting working memory development in secondary school students. This review critically evaluates the research on the efficacy of teaching strategies, screening protocols, and universal and targeted interventions for students with working memory difficulties.

By systematically analyzing the extensive body of research on working memory in secondary schools, this review aims to consolidate existing knowledge and identify research gaps. The synthesis of these findings contributes to advancing theoretical understanding and practical implications in supporting working memory development and academic success in secondary school students.

Allen Baddeley’s Model of Human Working Memory

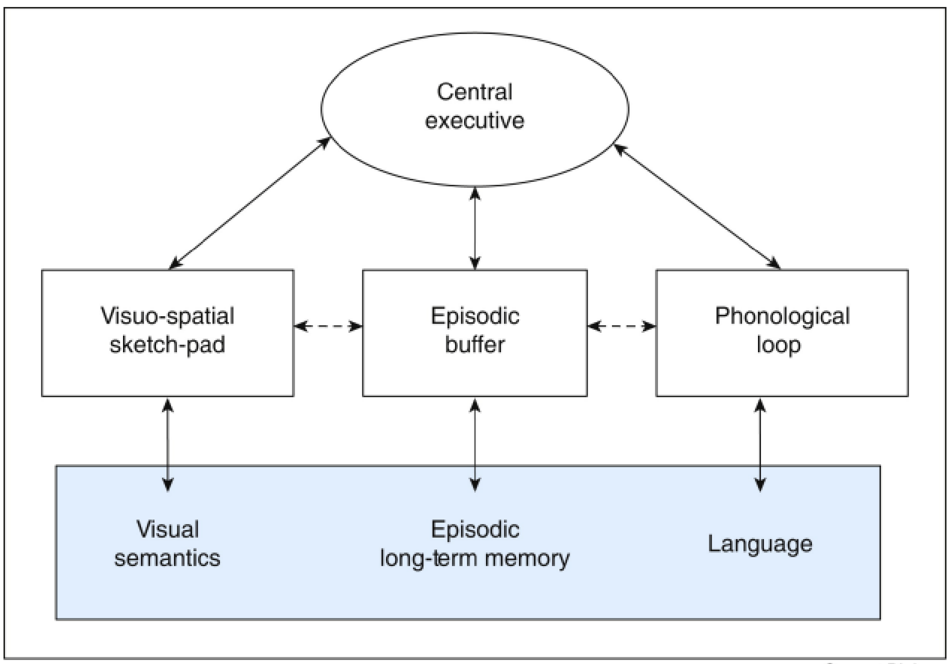
Baddeley's model of human working memory, also known as the Multi-Component Memory Model, is a theoretical framework proposed by Alan Baddeley and Graham Hitch in 1974; it has significantly impacted our understanding of human cognition and influenced cognitive psychology. The working memory model was developed as an alternative to the previously dominant view of short-term memory, which was seen as a single, unitary system for temporarily storing information. Baddeley and Hitch argued that short-term memory is more complex and consists of multiple components that support different cognitive processes.

The model described in Baddely (2010) proposes three main components of working memory: 1) the central executive, which controls and coordinates cognitive processes; it allocates attention to different tasks, manages resources, and integrates information from the other two components; 2) the phonological loop, which deals with auditory and verbal information; it is further divided into two subcomponents: the phonological store (inner ear), which holds auditory information for a brief period, and the articulatory rehearsal process (inner voice), which allows for the subvocal repetition of information to maintain it in memory, and 3) The visuospatial sketchpad, which is responsible for processing and manipulating visual and spatial data. It allows us to mentally visualize objects, remember spatial relationships, and perform mental imagery tasks. Baddeley later expanded the model to include an episodic buffer, a temporary storage system that integrates information from the phonological loop, visuospatial sketchpad, and long-term memory.

Dual-task experiments, such as Hitch’s (1988) digit span task combined with verbal reasoning, provided substantial evidence for the Multi-component Model. A dual-task memory test is a cognitive assessment that involves performing two separate memory tasks simultaneously; it measures a person's ability to divide their attention between multiple memory-related activities. In this test, individuals are typically presented with two sets of information or stimuli and must process and remember them simultaneously. The tasks can involve various types of memory, such as verbal memory, visual memory, or working memory. These experiments demonstrated that participants faced difficulty performing two tasks relying on the same system but could successfully handle tasks involving different slave systems simultaneously (Hitch et al., 1988). The revised version of Baddeley's Multi-Component Working Memory Model is presented in the accompanying diagram.

Figure 1.

Revised Working memory Model from Baddeley (2010).



The significance of Baddeley's model lies in its ability to explain various cognitive phenomena and guide research in cognitive psychology. It provides a more comprehensive account of the workings of short-term and working memory, offering insights into how we process and manipulate information in real time. The model has been influential in explaining a wide range of cognitive tasks, such as language comprehension, problem-solving, and decision-making. Furthermore, Baddeley's model has been influential in developing interventions and techniques for improving working memory capacity. It has also provided a foundation for understanding cognitive impairments associated with conditions like attention deficit hyperactivity disorder (ADHD) and Alzheimer's disease.

Working Memory Development During Adolescence

This section explores the development of working memory between the ages of 10 and 19. This section considers the influence of age-related changes in structural brain maturation, physiology, and psychology systems associated with changes in working memory abilities over time. This section is the first to analyze scientific investigations on working memory.

Puberty

Master et al. (2020) and Fung et al. (2020) are two studies that shed light on the intricate relationship between pubertal development, cognitive processes such as working memory, and neural activity, providing valuable insights into the dynamic interplay between hormones and brain maturation during adolescence.

Master et al. (2020) explored the various cognitive systems that contributed to changes in learning during adolescence. The researchers aimed to disentangle these systems and understand how they changed during this developmental period. They investigated the cognitive processes of working memory and reinforcement learning and their associations with neural processes, specifically the dopamine system. The study utilized a cross-sectional analysis involving 191 children and 55 adults to assess working memory and reinforcement learning performance. The researchers manipulated cognitive load and stimulus complexity to investigate their effects on learning. The findings revealed that working memory performance improved with the onset of puberty, while participants aged 13-17 demonstrated working memory capacities similar to adults. However, the individual contributions of reinforcement learning and working memory to learning could not be distinguished in this study. The research provided valuable insights into the developmental changes in learning during adolescence and highlighted the importance of understanding the interplay between cognitive processes and neural systems.

Fung et al. (2020) conducted a longitudinal study to examine the relationship between pubertal testosterone levels and the development of brain regions involved in visuospatial processing, specifically focusing on working memory. They collected data from adolescents, measuring testosterone levels and using EEG recordings to assess neural oscillatory activity associated with visuospatial processing. The results revealed a significant association between pubertal testosterone levels and the developmental trajectory of neural activity related to working memory. Higher testosterone levels were linked to increased neural activity in working memory-related regions, suggesting a role for hormonal changes during puberty in the maturation of neural circuitry supporting working memory. However, the study's limitations include a relatively small sample size and a focus on specific cognitive domains. Future research should explore the broader effects of pubertal hormones on cognitive development. Overall, this study provides valuable insights into the impact of hormonal changes on neural maturation during adolescence and calls for further investigation into the cognitive implications of pubertal hormones.

Structural Brain Maturation

The next literature example delves into a groundbreaking study that established a significant connection between the structural maturation of specific brain regions and the development of working memory. Later, a meta-analysis is presented, examining the association between improvements in working memory performance and cortical thinning in the frontal and parietal cortices. These two literature examples collectively highlight the compelling findings that support the strong relationship between the maturation of these brain regions, characterized by cortical thinning, and the developmental trajectory of working memory during adolescence.

Tamnes et al. (2013) provided the first evidence of a significant positive association between improvements in working memory performance and cortical thinning in the frontal and parietal cortices. Cortical thinning refers to a reduction in the thickness of the cerebral cortex, which is the brain's outer layer responsible for higher cognitive functions. Researchers employed a longitudinal design spanning two years, involving multiple assessments of working memory performance and magnetic resonance imaging (MRI) scans. The study included 111 participants, aged 8 to 22 years, who underwent two waves of assessments. Working memory performance was measured using a digit span task, while MRI reports were used to assess cortical thickness.

Tamnes et al. (2013) found that the degree of verbal working memory improvement decreased linearly with age, such that by the time a human is approximately 16 years of age, they have working memory ability comparable to that of a young adult, corroborating the cross-sectional analyses of Master et al. (2020) seen in the previous section of this review. Another trend seen in both studies was that increases in cognitive load did not significantly impact young adult working memory. In contrast, individuals 8-12 performed worse on working memory tasks under high cognitive load. Finally, Tamnes et al. (2013) found significant variation in the individual rate of brain maturation across study participants. While this study provides valuable insights into the relationship between working memory development and brain maturation, it is essential to consider some limitations. The sample size is relatively small. Additionally, the study primarily relied on correlational analyses, which do not establish causality.

Andre et al. (2016) provided a valuable synthesis of existing research on working memory development in healthy adolescents. Through systematic review and meta-analyses, the authors aimed to examine the changes in working memory processes as a function of increasing age during this critical developmental period. The review systematically investigated relevant studies to provide a large dataset of neuroimaging findings on healthy adolescents, allowing for comprehensive meta-analyses. The meta-analyses provided a quantitative synthesis of the included studies, enabling the identification of consistent patterns and trends across the literature. The analysis focused on brain regions associated with working memory, such as the prefrontal cortex, parietal cortex, and other regions within the working memory network.

The authors reported an age-related increase in prefrontal and parietal cortex activation during working memory tasks, suggesting a strengthening of working memory ability with age. These findings support the notion of ongoing maturation and optimization of the neural networks involved in working memory during adolescence. The authors highlighted the potential implications of the observed age-related changes in working memory abilities, such as improved cognitive abilities and better executive functioning as adolescents progress through adolescence.

One strength of this review is the systematic and comprehensive approach to synthesizing the available literature. Including meta-analyses enhances the findings' reliability and generalizability, providing a robust understanding of working memory development during adolescence. The article also acknowledged limitations, including the reliance on cross-sectional studies and the variability in methodologies across the included studies. These findings contributed to our understanding of the neural mechanisms underlying working memory development, highlighting the dynamic nature of the working memory network during this critical period of cognitive maturation.

Emotional Changes During Adolescence

The following article explores the relationship between working memory, emotional regulation, and behavioral outcomes in typically developing adolescents aged 10-19. The findings of this investigation have implications for schools, suggesting that interventions targeting working memory could positively impact emotional regulation and behavioral outcomes in adolescent students. Malagoli & Usai (2018) conducted a systematic literature search of various databases to identify studies examining the relationship between working memory, emotional regulation, and adolescent behavioral outcomes. The inclusion criteria were studies that used objective measures of working memory, emotional regulation, and behavioral outcomes and focused on typically developing adolescents aged 10-19. The search strategy yielded 33 studies that met the inclusion criteria. The authors used a narrative synthesis approach to analyze and summarize their findings. The reviewed studies used various research methods, including cross-sectional and longitudinal designs, experimental and correlational designs, and behavioral and neuroimaging measures.

The studies consistently demonstrated that working memory is strongly associated with emotional regulation and the development of adaptive behavior in adolescents. Specifically, adolescents with poor working memory abilities were more likely to experience difficulties with emotional regulation and display maladaptive behaviors such as impulsivity, aggression, and risk-taking. Conversely, those with better working memory abilities were found to have better emotional regulation skills and display more adaptive behaviors. Furthermore, the studies reviewed suggest that the relationship between working memory and emotional regulation is bidirectional, meaning that poor emotional regulation can also impair working memory abilities. Researchers also found that adolescents have higher rates of anxiety, depression, and use of maladaptive coping strategies (ex., rumination, externalized violence, self-harm) than other age populations.

This research indicated that interventions targeting working memory or emotional regulation could positively affect both domains. Overall, the studies reviewed in the article provide strong evidence supporting the relationship between working memory, emotional regulation, and behavioral outcomes in adolescence. However, the authors noted that the studies varied in their methodological rigor, and more research is needed to further understand the mechanisms underlying these relationships and to develop effective interventions.

Summary

This section has examined various aspects of working memory development during adolescence. It has explored the influence of age-related changes in brain maturation, physiological factors, and psychological systems on working memory abilities. Puberty has been identified as a critical period associated with changes in cognitive processes, including working memory. Studies have focused on disentangling the neural systems involved in working memory and reinforcement learning, which is associated with the dopamine system. These studies have demonstrated that working memory gains are associated with the onset of puberty, higher scores on pubertal development questionnaires, and increased testosterone concentrations.

Structural brain maturation has also been found to play a role in working memory development. Longitudinal studies utilizing structural magnetic resonance imaging (MRI) techniques have shown that improvements in working memory performance are related to cortical thinning in the frontal and parietal cortices. These findings suggest that the maturation of specific brain regions is associated with the development of working memory during adolescence. The review of existing literature on working memory development in healthy adolescents has highlighted the strengthening of the working memory processes with age. Meta-analyses of neuroimaging studies have revealed age-related increases in prefrontal and parietal cortex activation during working memory tasks, indicating ongoing maturation and optimization of the neural networks involved in working memory.

Lastly, the relationship between working memory, emotional regulation, and adolescent behavioral outcomes has been extensively studied. Adolescents with poor working memory abilities have been found to experience difficulties with emotional regulation and display maladaptive behaviors, while those with better working memory abilities demonstrate better emotional regulation skills and display more adaptive behaviors. The bidirectional relationship between working memory and emotional regulation suggests that interventions targeting either domain could positively affect both.

These findings provide valuable insights into the development of working memory during adolescence and highlight the complex interplay between cognitive, neural, and emotional factors. Further research is needed to deepen our understanding of these processes and to develop effective interventions that promote healthy working memory development in adolescents.

The Role of Working Memory in Learning During Adolescence

Working memory is an essential cognitive skill that allows individuals to temporarily hold and manipulate information in their minds. It is crucial for academic success as it plays a significant role in many academic tasks, such as reading comprehension, problem-solving, mental calculation, and learning new information. Research suggests that working memory is positively related to academic achievement, particularly in reading and mathematics. Students with stronger working memory skills tend to have better academic performance and are more likely to succeed in school. This section examines literature explaining how working memory interacts with functioning in the school setting. First, this section looks at working memory related to general intelligence. Then research is presented about how working memory abilities interact with learning specific subjects, like math and literature.

General Intelligence

Understanding how working memory impacts learning can inform interventions and strategies to support students' cognitive development and academic success. The next research example examines the predictive role of working memory and IQ in academic attainment. Alloway & Alloway (2010) conducted a longitudinal study with a sample of 164 UK children (82 girls and 82 boys) aged 5 to 11 years. The children were assessed on working memory performance, IQ, phonological awareness, rapid automatized naming, and academic attainment in reading, spelling, and math over a period of two years. Working memory was measured using two subtests from the Automated Working memory Assessment (AWMA: is a computerized cognitive test that is designed to assess working memory. The test assessed several components of working memory, including verbal and visuospatial working memory, central executive functioning, and attentional control.). IQ was measured using the Kaufman Assessment Battery for Children (KABC-II). Phonological awareness (ability to recognize and manipulate the sounds of spoken language) was measured using two subtests from the Comprehensive Test of

Phonological Processing (CTOPP: a standardized test used to assess phonological processing skills, which refer to the ability to process the sounds of spoken language.), and rapid automatized naming (is a cognitive task that measures the speed and efficiency of visual information processing and retrieval from long-term memory) was measured using two subtests from the CTOPP as well. Academic attainment in reading, spelling, and math was assessed using standardized tests, and the scores were used as dependent variables in the analyses. The authors used structural equation modeling to investigate the predictive roles of working memory and IQ in academic attainment, while controlling for age and socio-economic status. They also conducted analyses to investigate the indirect effects of Working memory on academic attainment via phonological awareness and rapid automatized naming.

The study found that both working memory and IQ were significant predictors of academic attainment in all three subjects of reading, spelling, and math. However, working memory was a stronger predictor of academic attainment in reading and spelling than IQ, while IQ was a stronger predictor of academic attainment in math. The study also found that the relationship between working memory and academic attainment was mediated by phonological awareness and rapid automatized naming. In other words, the association between working memory and academic attainment was partly explained by the role of working memory in supporting the development of these foundational skills. The findings suggested that working memory and IQ are both important predictors of academic attainment, but they have different roles depending on the specific academic domain being studied. The authors suggest that interventions aimed at improving academic attainment should target both working memory and IQ and consider the specific demands of each academic subject. The study also highlighted the importance of early intervention, as the effects of working memory and IQ on academic attainment were observed over a period of two years.

One limitation of the study was its' small sample size of 164 children from only two primary schools in the UK. This limits the generalizability of the findings to other populations and contexts. Additionally, the study only investigated academic attainment in reading, spelling, and math, and did not explore other subjects or areas of academic achievement. Another limitation is that the study used a limited number of cognitive measures to assess working memory, IQ, phonological awareness, and rapid automatized naming. There may be other cognitive abilities that were not assessed in the study, which could also have an impact on academic attainment. Finally, the study was conducted over a relatively short period of two years, and it is unclear whether the effects of working memory and IQ on academic attainment would persist over a longer period.

Working Memory and Academic Achievement

The following literature examples highlight evidence suggesting that recollection, working memory, and updating capacity are essential for learning and academic achievement, impacting standardized assessment scores in math and reading and influencing math growth rates and achievement from kindergarten to ninth grade. These cognitive processes play crucial roles in supporting academic success across various domains.

The relationship between visuospatial working memory and mathematical performance in school-aged children has been extensively studied, revealing a significant and positive association. Allen et al. (2019) systematically reviewed research studies investigating the relationship between visuospatial working memory and mathematical performance in school-aged children. The authors searched relevant literature using multiple databases, resulting in 35 studies that met the inclusion criteria for their review. After selecting the studies, the authors used a narrative synthesis approach to analyze and summarize the findings. They organized the studies into four categories based on the visuospatial working memory task type used: visual-spatial sketchpad tasks, mental rotation tasks, spatial span tasks, and other tasks (e.g., visual-spatial paired associates). The authors also examined the quality of the studies using the Cochrane Risk of Bias tool, which assesses the potential for bias in randomized controlled trials. They found that the studies included in the review had a high risk of bias in several areas, including blinding and randomization.

The review's findings suggested a moderate to strong positive relationship between visuospatial working memory and mathematical performance in school-aged children. The relationship was consistent across a range of measures of visuospatial working memory, including tasks that required mental rotation, spatial span, and visual-spatial sketchpad. The relationship between visuospatial working memory and mathematical performance was also consistent across different mathematical domains, including arithmetic, geometry, and problem-solving. The review also found evidence of a bidirectional relationship between visuospatial working memory and mathematical performance, suggesting that improvements in visuospatial working memory may lead to improvements in mathematical performance and vice versa. However, the authors note that the direction of causality is still unclear, and more research is needed to establish the nature of this relationship.

Blankenship et al. (2015) investigated the contributions of working memory and recollection to academic performance in math and reading in typically developing children. The study included 81 participants, and standardized tests were used to assess math fluency, calculation, passage comprehension, and reading fluency. Researchers utilized a longitudinal design to investigate the contributions of working memory and recollection to academic achievement in math and reading. The study included participants in an ongoing emotional and cognitive development study, with a mean age of 10.38 years. The participant group was predominantly Caucasian (89%) with highly educated parents (99%). This study employed statistical analyses, including multiple regression, to examine the relationships between working memory, recollection, and academic achievement in math and reading. The study found that both phonological and visuospatial working memory and recollection contributed distinctly to standardized assessment scores in all four areas examined (math fluency, calculation, passage comprehension, and reading fluency). Stronger working memory of both modalities (phonological and visuospatial) contributed positively to all four measures. However, the study's sample size was relatively small, and the lack of diversity among participants indicates a need for further research.

Bull & Lee (2016) is another example of a study examining the relationship between two cognitive processes, in this case, as they relate to math achievement by age. Researchers looked at the development of two executive functions related to math achievement: working memory and updating. Updating is a memory-related process defined in this study as responsible for " the addition and deletion of contents from working memory.". To eliminate the need for participants to rely on prior math knowledge during the assessment, researchers used a standardized assessment of numerical operations for a scale that could be applied across grades. Researchers deployed a cross-sectional design utilizing 673 participants designated into four different age groups (mean age of the four groups = 5.72 years, 7.85 years, 10.05 years, 12.32 years). For four years, participants reported annually for examinations testing measures of updating (pictorial updating), working memory (listening recall), performance intelligence, reading, and math tasks.

This study contributed to understanding the patterns of memory related to cognitive development. An important finding was that working memory and updating capacity at kindergarten predicted the average math growth rate until the ninth grade. Working memory capacity predicted math achievement in all grades. Researchers found a shift in grades 5-9 where working memory and updating capacity showed a weaker predictive relationship with math achievement; at the same time, prior math knowledge became a significant predictor of math achievement. Researchers attributed this finding to the progression of the Numerical Operations task, which increases in difficulty according to the participant's grade. Another significant finding was that the working memory and updating capacity development rate were not significantly different between individuals.

Summary

This section focused on the role of working memory in academic settings, specifically its relationship with general intelligence, math achievement, and learning processes. The first study of this section by Alloway & Alloway (2010) explored the predictive roles of working memory and IQ in academic attainment. They found that both working memory and IQ significantly predicted academic achievement in reading, spelling, and math, with working memory being a stronger predictor in reading and spelling, while IQ was stronger in math. The study also revealed that phonological awareness and rapid automatized naming mediated the relationship between working memory and academic attainment. The second study, Allen et al. (2019) found a consistent and positive relationship between visuospatial working memory and mathematical performance across various tasks and domains. The review also suggested a bidirectional relationship, implying that improvements in visuospatial working memory could lead to better mathematical performance and vice versa.

The section also discussed Blankenship et al. (2015), which investigated the contributions of working memory and recollection to academic performance in math and reading. They found that both phonological and visuospatial working memory and recollection had distinct contributions to standardized assessment scores in math fluency, calculation, passage comprehension, and reading fluency. The study suggested that working memory and recollection play important roles in academic achievement. Finally, Bull & Lee (2016) examined the relationship between working memory, updating capacity, and math achievement across different age groups. They found that working memory and updating capacity at kindergarten predicted the average math growth rate until the ninth grade, with working memory capacity being a consistent predictor of math achievement in all grades. However, the predictive relationship weakened in grades 5-9 as prior math knowledge became a significant factor.

These studies highlight the significance of working memory in academic success, particularly in reading and math. They emphasize the importance of interventions that target both working memory and IQ, considering the specific demands of each academic subject. Additionally, the studies in this section shed light on the relationship between visuospatial working memory and mathematical performance and the role of working memory in learning.

The Interplay Between Working Memory and Stress

This section reviews the research on the relationship between working memory and stress, specifically focusing on its implications for classroom learning. Acute stress, characterized by the release of stress hormones, has been found to have a negative impact on working memory, potentially affecting cognitive performance in the classroom. Moreover, evidence suggests that chronic stress can significantly compromise working memory functioning and cognitive processes, further highlighting the potential implications for learning and academic achievement in the classroom setting. The studies discussed in this section support the notion that acute and chronic stress can impair working memory performance, emphasizing the importance of addressing stress and its impact on cognitive abilities in educational settings.

Acute Stress

Acute stress, such as the stress experienced before a test or presentation, can trigger performance anxiety, negatively impacting cognitive functioning and learning. Research suggests that performance anxiety can impair working memory, attention, and information processing, reducing academic performance. Researchers for The Language Research Center at the University of Georgia were recently interested in investigating the phenomenon of performance anxiety from an evolutionary perspective. Sosnowski et al. (2022) conducted research with a captive population of Capuchin Monkeys. Quantitative data was collected from test subjects to determine individual performance differences during trained tasks that require working memory processing. Researchers sought to provide information about the biologically derived influences of performance anxiety instead of the well-studied psychosocial influences (ex. Parent/teacher expectations, peer group norms).

Researchers trained the monkeys to associate a high value reward with a high stake computerized delayed-match-to-sample task (DMTS); Likewise, they were given and a low value reward following completion with a low stakes task, difficulty of the computerized task remained the same. A delayed-match-to-sample task (DMTS) is a cognitive task commonly used in research to assess working memory and short-term memory abilities in humans and animals. The task involves presenting a sample stimulus, which is then removed from view after a short delay, followed by the presentation of a test stimulus. The participant or animal must indicate whether the test stimulus matches the sample stimulus.

Each of the 20 test subjects was tested in over 200 trials completed in 15 sessions. To determine the relationship between memory performance and cortisol levels, 124 fecal samples were collected over the course of the study and analyzed using an enzyme immunoassay validated for use in Capuchin Monkeys. Results of one-way ANOVA analysis revealed that, like humans, capuchin monkeys show individual discrepancies in performance between high-stakes and low-stakes tasks. Data analysis did not reveal a group-wide relationship between pressure (high-stakes testing) and performance. Statistical analysis also found a significant inverse relationship between cortisol level and individual proclivity to “choke” or “thrive” during the DMTS task.

Regarding method validity, the DMTS task may not have assessed the working memory of the capuchin monkeys as manipulation during the task was not required, making this a test of declarative memory instead. In their discussion on research limitations the author notes that the first few sessions may have captured a more realistic description of the monkey’s performance under pressure. Researchers wrote that as the sessions progressed, practice and external motivators might influence the monkey’s ability to perform. This experimental study illuminated the biological underpinnings influencing individual performance on high-stakes tasks. These insights clarify cognitive discrepancies related to anxiety in the classroom; for example, performance on high-stakes testing or other tasks that students have previous experience/success with but show variable results under pressure.

The next literature example highlights the importance of managing and reducing performance anxiety to optimize learning outcomes to create a conducive classroom environment that supports students' cognitive processes and academic success. The principal researcher in Quervain et al. (2000) is notable for numerous contributions to neuroscience that focus on memory and phobias. This study was significant at the time of publication because researchers examined a specific phase of memory rather than looking generally at the memory phases together (i.e. information encoding, memory consolidation, and long-term memory retrieval). This study employed a double-blind, placebo-controlled with-in-subject test design to assess how exogenous cortisol (naturally produced by the adrenal glands in response to stress or other stimuli) modulates declarative memory retrieval. Declarative memory retrieval is an essential step in the working memory process as it allows individuals to access stored information and apply it to new scenarios and problems.

Participants were shown a list of nouns for four seconds and instructed to visualize them with the intention of remembering them until two weeks after learning. Participants were given a blank sheet of paper to determine free recall and asked to write as many nouns as they could remember from the word presentation. Participants were given a list of 60 nouns to assess word recognition and asked to indicate which were on the word presentation from two weeks prior.

Participants were randomly assigned to groups receiving either the control treatment (25 mg of mannitol), or the experimental treatment (25 mg of cortisone). Experimental groups were administered cortisone at different times: one hour before the delayed recognition/recall test, one hour before the initial word presentation, and one hour after the initial word presentation. After the initial two-week period, test subjects returned to the lab to participate under different treatment conditions; this occurred four times until each participant experienced each treatment (drug administration pre/post learning or pretesting).

Results of a paired t-test analysis showed significant impairment of word recall for individuals who were administered cortisone one hour prior to the free recall test as compared to individuals in the placebo group. Statistical analysis did not provide evidence of significant recognition impairments for any of the experimental groups. Subjects who received oral cortisone pre and post word presentation were not affected in the areas of recall or recognition, in fact participants who received cortisone one hour before their learning session had higher measures of word recognition and recall. This research suggests that stress hormones, such as cortisol, can positively and negatively affect memory. In the short term, moderate cortisol levels may enhance memory by increasing attention and improving brain information consolidation. These findings are significant because they help to display the cognitive deficits created by everyday classroom stressors, specifically high-stakes quizzes and tests. To acknowledge this research in the classroom would pay homage to the scientific basis of test anxiety and differences in actual memory ability versus under stressful circumstances.

There are several limitations of this study. According to the Cochran formula, the sample size of this study is not large enough to estimate a population trend with confidence. Validity and design wonderings aside, I selected this study to review because it does reinforce what previous animal subject studies and subsequent human subject studies have found concerning declarative memory – that is, that the physiological response to stress can enhance memory processes during encoding (converting incoming sensory information into a format that the brain can use and process) and hinder memory retrieval in humans.

Understanding and addressing the impact of acute stress and stereotype threat on working memory is crucial for creating inclusive learning environments that promote optimal cognitive functioning and mitigate the negative effects of stereotypes on academic achievement. The next literature example investigated the intersection of acute stress, working memory, and stereotype threat in the context of learning. Stereotype threat is when individuals belonging to a particular social group experience anxiety and fear of confirming negative stereotypes about their group.

Rydell et al., (2009) randomly assigned participants to either a stereotype threat or control condition. The stereotype threat condition involved participants being told that the study was examining cognitive abilities related to gender or race, while the control condition did not mention these categories. The researchers measured working memory performance using a digit span task, which required participants to recall a series of numbers in the correct order. The study also used a priming task to manipulate the accessibility of social identities. In the priming task, participants were shown pictures of faces that varied in gender and race and were asked to identify the gender or race of each face. Participants were either presented with an equal number of male and female or Black and White faces or an unequal number that created an imbalance in accessibility. The study used a 2 x 2 design, with stereotype threat (present or absent) and accessibility balance (balanced or imbalanced) as the independent variables. The dependent variable was the accuracy of participants' digit span task performance. The study used 172 undergraduate students as participants, and the data were analyzed using ANOVA and regression analyses.

In the study, the researchers conducted three experiments to examine the impact of stereotype threat on working memory and how the effects could be mitigated. In the first experiment, participants were randomly assigned to a gender identity prime or control condition before completing a working memory task. The results showed that women in the gender identity prime condition performed worse on the working memory task than those in the control condition, indicating the presence of stereotype threat. In the second experiment, participants were primed with multiple identities (e.g., gender and college major) before completing a working memory task. The results showed that the negative effects of stereotype threat on working memory were reduced for participants with multiple identities compared to those with only one identity. In the third experiment, participants were primed with multiple or only one identity before completing a working memory task under high or low cognitive load conditions. The results showed that participants with multiple identities performed better on the working memory task under high cognitive load conditions compared to those with only one identity, indicating that multiple identities can serve as a buffer against stereotype threat effects on working memory.

The findings of the study have several implications for educational settings. For instance, the study suggests that individuals with multiple social identities may be particularly vulnerable to stereotype threats, which can negatively impact their working memory and cognitive performance. Therefore, creating inclusive and supportive environments that acknowledge and value the diversity of individuals' social identities is important. Additionally, the study highlights the importance of reducing stereotype threat to improve cognitive performance and working memory. This can be achieved through various interventions, such as educational programs and workshops, that promote awareness and understanding of stereotype threat and its effects. One limitation of the study is that researchers used a laboratory setting and may not fully reflect stereotype threat's complex and dynamic nature in real-world settings. Therefore, further research is needed to explore the generalizability and practical applications of the study's findings.

Chronic Stress

Chronic stress refers to a prolonged state of physiological and psychological tension or strain that persists over an extended period. Chronic stress can have a significant impact on students' lives, as they often face numerous academic, social, and personal pressures. Chronic stress not only affects working memory but also has significant implications for learning. When individuals are exposed to chronic stress, their cognitive processes, including working memory, can be disrupted, which in turn hinders their ability to learn and retain new information effectively. Hawkins et al. (2021) is an example of research that investigated the relationship between working memory and chronic stress during adolescence.

Hawkins et al., (2021) used data from the National Longitudinal Study of Adolescent to Adult Health, which provided a nationally representative sample of adolescents in the United States. The sample for this study included 13,113 participants who completed cognitive assessments during the fourth wave of data collection (in 2007-2008) when they were aged 24-32 years. The cognitive assessment battery included working memory, verbal fluency, and processing speed measures. Adverse childhood events were assessed in Wave 1 of the study through self-report of 11 types of abuse, neglect, and household dysfunction. The study controlled for demographic factors such as age, sex, race/ethnicity, and parental education. Working memory was assessed using the Digit Span Backward test, which measures the ability to hold and manipulate information in short-term memory. Verbal fluency was assessed using the Controlled Oral Word Association Test, which measures the ability to generate words beginning with a specific letter. Processing speed was assessed using the Digit Symbol Substitution Test, which measures the speed of visual-motor processing and working memory. The researchers conducted linear regression analyses to examine the relationship between adverse childhood events and cognitive function, controlling for demographic factors and baseline cognitive function. They also examined whether the relationship between adverse childhood events and cognitive function varied by sex or race/ethnicity by including interaction terms in the regression models.

Hawkins et al., (2021), found that adverse childhood events were negatively associated with working memory among young adults. Researchers noted that individuals who experienced more adverse childhood events had lower working memory scores than those who experienced fewer. This association remained significant even after controlling for demographic factors such as age, sex, race/ethnicity, health behaviors, and mental health. However, the association between adverse childhood events and working memory was partially explained by current stress and depressive symptoms. The study also found that the association between adverse childhood events and working memory was not significantly moderated by sex or race/ethnicity. However, there was a significant interaction between adverse childhood events and education, such that the negative association between adverse childhood events and working memory was stronger among those with higher levels of education. Overall, the study suggests that adverse childhood events may have long-lasting effects on working memory, potentially impacting academic and occupational outcomes. The study highlights the need for interventions and support for individuals who have experienced adverse childhood events, especially those with higher levels of education.

Socioeconomic status (SES) and chronic stress are interconnected factors that significantly impact students' well-being. Lower income levels and financial strain, often associated with lower SES, contribute to chronic stress due to the constant worry and pressure related to meeting basic needs. The authors of Raffington et al., (2018) sought to address the gap in knowledge concerning the relationship between Socioeconomic Status (SES) predictors, Cortisol Stress Reactivity (CSR), Cortisol Awakening Response (CAR) and cognitive abilities in prepubescent students. 147 students aged 6-7 years old were enlisted in this quantitative study. Participants were selected from six school districts representing lower and higher family SES respectively. Parents were instructed to collect salvia samples for cortisol level analysis (CAR and CSR). Student guardians reported SES status. Memory ability was measured with an associative memory task. The Trier Social Stress Test for children was used to determine psychosocial indicators of CSR. Additional hippocampal structures and volumes were examined using an MRI machine.

Statistical analysis indicated a significant association between students from low-income families and a damped CAR and CSR. Hyperreactivity to acute stress was associated with lower memory performance scores only in students from low-income families. While students residing in low-income homes had a blunted response to acute psychosocial stress, they had strong stress responses to the low-challenge stimuli. Finally, hippocampal volume was not associated with cortisol levels or lower memory performances. Because this study found no association between CSR and memory, researchers deduce that there may be a threshold effect on the processes linking environmental stressors to memory function; therefore, only students at the lowest end of the SES spectrum may be affected. This research is significant because it's claims that hippocampal volume was not associated with Working memory performances. Research in this area often suggests that structural brain changes caused by exposure to adverse childhood events (like living in poverty) are the reason cognitive abilities may decrease.

Summary

This section explored literature covering the relationship between working memory and stress. It summarized several studies that investigate the impact of acute and chronic stress on working memory performance. The studies reveal that acute stress can impair working memory performance, while chronic stress can lead to decreased working memory capacity. The findings suggest that both types of stress can have a negative effect on working memory. However, the research also acknowledges the need for further studies to fully understand this relationship and identify strategies to mitigate the negative effects of stress on cognitive function. This section highlights the importance of considering biological and psychosocial factors, such as cortisol levels, performance anxiety, and stereotype threat, in understanding the interplay between working memory and stress. The studies provide insights into the cognitive deficits created by stressors, such as high-stakes testing and adverse childhood events, and emphasize the importance of creating supportive environments and interventions to enhance cognitive performance and protect working memory from the detrimental effects of stress.

Supporting Working Memory Development in Schools

This section examines working memory interventions from a multitiered perspective of support. I begin with literature addressing early intervention and screening protocols for students with working memory Difficulties. Next, I review the literature investigating the far transfer effects of targeted Tier 3 Working memory interventions. Then I look at how general education teachers incorporate strategies and pedagogical practices into small groups or class-wide settings as part of Tier 2 level support. Lastly, I outline research on the efficacy of Tier 1 universal programs that enhance executive functioning and social and emotional wellness in secondary schools.

Working Memory Screening in Schools

Because working memory consistently predicts future academic success, it is an interest in the field of education to develop working memory rating scales for screening and early detection. This topic reveals itself in the literature in attempts to validate working memory rating scales against direct measures of working memory. Working memory capacity is generally conceptualized in this field by the computerized automated working memory assessment (AWMA) or other dual-task performances common in cognitive neuroscience as assessments of working memory (Normand & Tannock, 2014). Many current assessments of working memory have received criticism in the literature because of their inability to detect real-life working memory capacities (Alloway, 2012; Hitch et al., 1988). Additional issues arise in the literature concerning the practicality of screening protocols in busy secondary classrooms and the ability to standardize working memory screening protocols across classrooms (Alloway, 2012; Normand & Tannock, 2014). There is not a clear consensus about the relationship between working memory rating scales and tests of working memory performance; however, some behavioral characteristics remain constant across studies of students with working memory differences.

In one such examination of working memory screening validity, Normand & Tannock (2014) asked the teachers of 524 students at the onset of adolescence (average age nine years old) to assess students in the classroom environment for indications of working memory challenges. Teachers were given a five-point memory rating scale to deploy during regular class sessions. When researchers compared the results of teacher screenings to the students' working memory ability indicated by the AWMA, they found that teacher-rated scores matched those of direct measure of working memory (Normand & Tannock, 2014)—in a previous study with an 18-month longitudinal design Alloway (2012) observed over 3,000 students with working memory difficulties where two-thirds of participants showed difficulty in the areas of reading and mathematics.

Because of the challenge of developing a working memory rating scale that adheres to realistic working memory demands and shows validity with a direct measure of working memory, a psychometric rating scale for the classroom is still being investigated. However, the common behavioral characteristics of students struggling with working memory in the classroom are consistent and are indicated in Table 2 below.

Table 2

Behavioral Characteristics of Students with Working Memory Differences

Behavior

Abandons task before completion or begins to make errors Place keeping errors (missing letters or words from sentences.

Benefits from continued teacher support during lengthy activities, needs help from adults to stay on task.

Does not follow classroom instructions accurately; forgets steps in the instructions; carries out some but not all instructions; forgetting length instructions.

Making poor progress in literacy and math, Greater academic difficulties.

Dependance on neighbors to remind them of the current task.

Difficulty organizing and completing tasks.

Trouble concentrating or coping with tasks that require mental effort.

Typically reserved in large teacher led activities.

Targeted Working Memory Interventions

CogMed is a cognitive training software program created by a neuroscientist who found that working memory challenges benefited his patient's long-term working memory abilities. CogMed now services seven different commercial software programs for individuals seeking solutions to their working memory and attention difficulties. Like many in the field of neuroscience, the Hitchcock & Westwell (2017) study was interested in evaluating the transfer effects of the CogMed working memory Training (CWMT) program on elements of academic life, specifically task-related attention in the classroom. This study was distinct from others in its exploration of the benefits of this program on aspects of social and emotional development in schools. This study focused on cognitive reappraisal, which responds flexibly to classroom demands and regulates one's emotions. Researchers posited that if the CWMT program does enhance an individual's ability to maintain task-related attention, it may also support students in controlling their attention to engage in adaptive thought patterns when confronted with emotional challenges.

Researchers employed a cluster randomized controlled trial to assess the impacts of direct working memory training on task-related attention (improved academic performance) and emotional regulation (fewer social/behavioral challenges in the classroom). A total of 148 students participated in the study from two different schools; the participant group had a mean age of 12.5 years. Classes were randomly assigned treatment groups to a CWMT group, a placebo group that received nonadaptive training, or a passive control that conducted class as usual. The treatment group completed computer-based working memory tasks every school day for forty-five minutes over the course of five weeks. The training consisted of interactive verbal and visuospatial tasks to challenge students' memory maintenance and ability to re-order and organize information.

Academic outcome measures were determined using standardized reading comprehension assessments composed of a short article reading and associated multiple-choice questions. Throughout the reading examination, thought probes were used to detect students' level of task-related attention. A sound would beep at predetermined intervals, indicating that students should record their thoughts in writing just before hearing the tone. Researchers categorized student responses as either task-related or task unrelated for the purpose of data analysis. Teacher-reported social, emotional, and behavioral competencies were recorded using the Child Behavioral Checklist (CBCL), a validated measure of both internal (ex., anxious thought patterns and external (ex. Rule-breaking, aggression) manifestations of emotional regulation difficulties.

After comparing data across study groups, researchers concluded that the CWMT program had no significant impact on academic outcomes, task-related attention, reading comprehension, or social, emotional, and behavioral ratings. While the CWMT did significantly improve students' ability to perform the program-specific tasks within that training program, these improvements did not transfer to teacher ratings of emotional well-being nor academic performance on standardized assessments. Researchers suggest future studies should focus on applying memory training to setting and subject-specific academic activities using strong scaffolding instead of the less transferable task-specific training model. There is still an open debate in the research on whether Working memory capacity can be improved or whether this process has a fixed ability.

Differentiation That Supports Working Memory in The Classroom

This section focuses on literature investigating classroom-based strategies and differentiation that general education teachers can implement. First, I discuss memory strategies; then I address instructional strategies and classroom differentiation that supports working memory performance in schools.

Memory Strategies. Working memory training shows varying degrees of efficacy on adolescents' attention control and emotional regulation measures. As a result, many researchers have examined compensatory strategies (strategies that mitigate the daily impacts of memory impairment) to improve memory functioning in realistic settings. Populations of individuals affected by working memory deficits caused by aging or acquired traumatic brain injury have provided strong empirical evidence supporting the effectiveness of memory strategies across environments and daily tasks.

Pizzonia & Suhr (2022) systematically reviewed existing peer-reviewed publications on internal and external memory strategies. After identifying potential articles, the authors screened the abstracts and full texts to determine their eligibility for inclusion. Studies that did not focus on internal or external memory strategies did not have an experimental or quasi-experimental design or did not report quantitative data were excluded from the review. The final sample included 30 articles that met the inclusion criteria. Data from each article were extracted and synthesized to identify common themes and trends related to internal and external memory strategies.

The review found that internal strategies, such as repetition and organization, were more effective than external strategies, such as note-taking and highlighting, for improving memory performance. However, the effectiveness of internal strategies varied based on the type of material being learned, with some strategies being more effective for verbal material and others for visual material. The review also found that combining internal and external strategies could lead to better memory performance than using either strategy alone. Finally, the review noted the importance of individual differences, such as cognitive ability and learning style, in determining the effectiveness of different memory strategies.

The author notes that one limitation of this review is that it only included peer-reviewed articles in English, which may have excluded relevant studies published in other languages. Additionally, there was variation in the studies' quality, with some lacking proper controls or blinding. Finally, there was limited research on using both internal and external memory strategies together, suggesting a need for further investigation in this area.

O'Neil-Pirozzi et al. (2010) was a randomized controlled trial that examined the effectiveness of Internal Memory Strategies (I-MEMS) in individuals with traumatic brain injury (TBI). The participants were 37 adults with mild to moderate TBI who were randomized to receive either an I-MEMS or a control intervention involving general cognitive rehabilitation. The I-MEMS intervention involved teaching participants specific strategies such as visualization, association, and elaboration to aid in encoding and retrieval information. The control intervention focused on general cognitive rehabilitation exercises that did not target memory specifically. Both interventions were conducted in 45-minute sessions twice per week for 8 weighteks. The study utilized multiple measures to assess memory function, including the California Verbal Learning Test-II (CVLT-II: a neuropsychological test that assesses verbal learning and memory abilities in individuals aged 16 years and older.), the Rivermead Behavioral Memory Test (RBMT: a neuropsychological test designed to evaluate different aspects of memory function, including immediate and delayed recall, recognition, temporal orientation, and prospective memory.), and the Memory Assessment Clinics Self-Rating Scale (MAC-S: a self-report questionnaire that assesses subjective memory complaints in individuals).

The study results showed that participants who received I-MEMS treatment significantly improved their memory function compared to those who did not. Specifically, they performed better on memory tasks related to recalling information, such as remembering lists of words and story details. Moreover, the improvements were maintained over time, with the I-MEMS group demonstrating better memory performance six months after the treatment ended. The study suggests that the I-MEMS program effectively improves memory function in individuals with TBI, and the strategies taught can be applied to various memory tasks and situations.

Instructional Strategies. Literature on this topic also recommends how compensatory memory strategies should be taught to individuals with memory differences. Evans et al. (2000) aimed to compare the effectiveness of two different learning methods, "errorless" and "trial-and-error," for teaching individuals with acquired memory deficits. The participants were 30 individuals with memory impairments resulting from brain injury, stroke, or other causes. The study used a randomized controlled design with participants assigned to either the errorless or trial-and-error group.

All participants underwent a baseline assessment to measure their memory abilities. They were then trained to learn 20 face-name pairs using either the errorless or trial-and-error method. After the training, the participants underwent a post-training assessment and a delayed retention assessment four weeks later. The errorless method involved providing the correct answer to the participant immediately after presenting the cue (i.e., the face). In contrast, the trial-and-error method required the participants to try to recall the name before receiving feedback. The errorless method was designed to minimize errors and prevent the consolidation of incorrect information, while the trial-and-error method was designed to promote active retrieval and consolidation of correct information. The study used a range of memory tests to assess the effectiveness of the two methods: immediate and delayed recall, recognition, and cued recall. The primary outcome measure was the percentage of correct responses on the immediate and delayed recall tests.

This study found that the errorless method was more effective than the trial-and-error method for teaching individuals with memory impairments. The errorless group showed significantly higher scores on the immediate and delayed recall tests compared to the trial-and-error group. The errorless group also showed fewer errors and higher levels of confidence in their responses. This study also found that the errorless method was more effective for individuals with severe memory impairments. In contrast, the trial-and-error method was more effective for individuals with mild to moderate memory impairments. Regarding limitations, this research was conducted in a laboratory setting, and the results may not generalize to real-world situations. This study did not measure long-term retention beyond four weeks, so it is unclear if the benefits of the errorless method would be sustained over a longer period.

Wilson & Evans (1996) is a conceptual paper that reviews the use of error-free learning in rehabilitating individuals with memory impairments. The authors do not report on a specific study and, therefore, do not describe any research methods. Instead, they provide an overview of the principles underlying error-free learning, the history of its use in memory rehabilitation, and its potential benefits compared to trial-and-error learning approaches. They also discuss the importance of individualized treatment plans and the need for ongoing evaluation of treatment efficacy.

Wilson & Evans (1996) involved ten participants with acquired memory impairments divided into two groups. The first group received an errorless learning approach, which involved presenting the correct answer to the participant immediately after a question was asked. The second group received a trial-and-error learning approach, which involved allowing participants to make errors and providing feedback to correct them. The study results showed that the group that received the errorless learning approach had significantly higher scores on memory tasks than the trial-and-error group. The errorless learning approach was also found to be more time-efficient compared to the trial-and-error approach. This study implies that the errorless learning approach can be an effective rehabilitation technique for individuals with memory impairments. This approach can also save time and reduce frustration, as it minimizes errors and provides immediate feedback.

Classroom Differentiation. Cognitive load refers to the amount of mental effort and resources required to process and handle information during a specific task. Researchers who believe that working memory has limited capacity also suggest that tasks with high cognitive load demand more mental resources, which can overload and strain the working memory system. When working memory becomes overloaded, it becomes more challenging to process and retain information effectively, leading to reduced cognitive performance.

Merriendoer & Paas, (2020), is a conceptual article that summarizes the implications of Cognitive-Load Theory in the classroom and proposes methods to manage working memory load in learning complex tasks. The authors discuss practical strategies for managing cognitive load in the classroom including using worked examples, segmenting tasks, and providing scaffolding. Some examples of these strategies and benefits are as follows: using worked examples, segmenting tasks, providing scaffolding, reducing the amount of information, and fostering a supportive learning. These strategies aim to reduce extraneous cognitive load leading to more effective learning outcomes. The authors also address educators about balancing cognitive load in the classroom regarding instructional design, stating that balancing cognitive load can be a complex task, as reducing extraneous cognitive load too much may lead to boredom or disengagement.

Some educational researchers have investigated environmental differentiation that can reduce students' cognitive load to free more working memory capacity. Llinares, Higuera-

Trujillo, and Serra (2021) aimed to investigate the effects of classroom color on students' attention and memory using psychological and neurophysiological measures. The study involved 53 students, and they were randomly assigned to either a cold-colored (blue-green) or warm-colored (red-orange) classroom for a session. The researchers used several measures to assess students' attention and memory, including the Attention Network Test (ANT: is a computer-based task that assesses three different attentional networks: alerting, orienting, and executive control.), the Stroop Test (a classic psychological test used to assess selective attention and cognitive control), and a memory task involving the presentation of word pairs. In addition, electroencephalography (EEG) was used to measure brain activity during the tasks.

The findings revealed that students in the warm-colored classroom performed better on the ANT, indicating better attentional control, than those in the cold-colored classroom. However, there were no significant differences in performance on the Stroop Test or the memory task. The EEG data showed that brain activity was different between the two groups, particularly in the areas related to attention and emotion processing. There were several limitations to this research. Mainly, the sample size was relatively small and the study only measured the immediate effects of classroom color on attention and memory and did not explore potential long-term effects. This study suggests that classroom color may impact students' attention and brain activity, but further research is needed to fully understand these effects and their implications for educational settings.

Holistic Supports for Working Memory Development

This section considers research investigating the efficacy of universal supports that may enhance students’ working memory performance at school. First, I discuss social and emotional learning programs that support students' social skills and executive functions; processes that co-develop with working memory during adolescence. Finally, I examine literature about later school start times that may support overall cognitive function at school.

Mindfulness-Based Social and Emotional Learning. There is growing research that suggests mindfulness training, as a component of SEL programs, can enhance working memory capacity and flexibility. By practicing mindfulness exercises that involve sustained attention and non-judgmental awareness, students may develop the ability to focus their attention and resist distractions. This improved attentional control may directly contribute to better working memory performance. Mindfulness-based SEL programs may also improve working memory by reducing cognitive load and mind wandering. This section reviews several studies that support the positive effects of mindfulness based SEL programs on working memory in students.

Jha et al. (2019) conducted a comprehensive review of the literature on the relationship between mindfulness training and working memory. They found that mindfulness training may improve working memory capacity, flexibility, attentional control, and reduce mind wandering (Jha et al., 2019). However, the effects of mindfulness training on working memory varied across studies. Some limitations identified in the reviewed studies included variability in training protocols, lack of control groups, small sample sizes, and a lack of long-term follow-up (Jha et al., 2019).

One program that incorporates mindfulness practices and therapeutic approaches is the "Learning to Breathe" (L2B) program, which is a typical SEL program offered in secondary schools in the United States. The L2B program defines mindfulness as "awareness and non-reactive experiencing of thoughts, emotions, and sensations without suppression or avoidance"

(Lam & Seiden, 2020). The program aims to be a Tier 1 universal intervention in schools (Lam & Seiden, 2020).

Frank et al. (2021) evaluated a teacher-delivered mindfulness-based curriculum in secondary schools. They provided teachers with extensive training and support and compared the treatment group to a control group that received instruction as usual. While the study did not find significant improvements in emotional regulation and stress-related somatic symptoms, it did find substantial improvements in selective attention and inhibitory control, suggesting a reduction in cognitive load (Frank et al., 2021).

Lam and Seiden (2019) examined the well-being outcomes of the L2B program when administered by one of the program developers. They found small to moderate effect sizes on stress reduction, self-compassion, emotional clarity/awareness, and mind wandering. Additionally, medium effect sizes were observed for the dynamic control and self-monitoring components of executive function, and a small effect size was seen for the working memory component of executive function (Lam & Seiden, 2019).

Both studies emphasized the importance of student engagement and the time spent practicing mindfulness exercises outside the classroom for achieving positive outcomes (Frank et al., 2021; Lam & Seiden, 2019). The implementation of the L2B program by trained teachers was found to be more effective than when delivered by outside professionals, although program fidelity varied (Lam & Seiden, 2020; Frank et al., 2021).

Later School Start Times. Research suggests that starting school later in the day aligns with the natural sleep-wake patterns of adolescents, who typically experience a delayed sleep phase during puberty. There is evidence that working memory performance can be supported by allowing students to get sufficient sleep, which is crucial for memory consolidation. Educational researchers have become increasingly interested in how later school start times can enhance working memory. In a systematic literature review, Marx et al. (2017) found that later school start times were associated with improved cognitive function among high school students. Specifically, several studies in the review found that later start times were associated with improved student attention, alertness, and working memory. The included studies used various research designs, including natural experiments and randomized controlled trials, and were conducted in different countries.

One study in the review found that delaying school start times by 30 minutes significantly improved attention and working memory among high school students. Another study found that later start times were associated with a 2.5% increase in student test scores. The authors of this review suggested that the benefits of last start times on cognitive function may be due to several factors. For example, later start times may allow students to get more sleep, which is important for cognitive function. Additionally, later start times may align better with students' natural circadian rhythms, which can impact their alertness and cognitive function.

One limitation of this review is that there was considerable heterogeneity in the studies included, making it difficult to draw definitive conclusions. For example, the studies varied regarding the students’ age, the intervention duration, and the outcomes measured. Additionally, many of the studies included in the review were observational or quasi-experimental, which limits researchers’ ability to make causal inferences. Factors other than school start times may have contributed to the observed improvements in cognitive function. The review suggested that later start times may benefit high school students’ cognitive function. Still, more research is needed to fully understand the mechanisms behind these benefits and the optimal timing and implementation strategies.

Summary

This section explored various aspects of supporting working memory development in schools. It began by discussing the importance of early intervention and screening protocols for identifying students with working memory difficulties. The section then examined targeted interventions at different tiers of support, including using cognitive training programs like CogMed. However, the literature notes that while these programs may improve specific tasks within the training program, they do not necessarily translate into improvements in academic performance or emotional well-being.

The section also addressed strategies for supporting working memory in the classroom, focusing on compensatory memory strategies. Internal strategies, such as repetition and organization, are more effective than external strategies, like notetaking or highlighting. This section suggests combining internal and external strategies can improve memory performance. It also highlights the effectiveness of teaching internal memory strategies, as seen in a study involving individuals with traumatic brain injury.

Furthermore, this section discussed instructional strategies for teaching students with working memory difficulties. Using errorless learning methods, which provide immediate correct answers, is more effective than trial-and-error methods, particularly for individuals with severe memory impairments. The benefits of errorless learning include higher memory task scores and increased response confidence.

Lastly, this section explored ways to reduce cognitive load in classrooms. Educators can promote more effective learning outcomes by optimizing instructional design and managing extraneous cognitive load. Strategies such as using worked examples, segmenting tasks, and providing scaffolding are discussed as practical approaches to reducing cognitive load. This section provides insights into the screening and intervention protocols for working memory difficulties and practical strategies for supporting working memory development in school settings.

Action Plan

This research aimed to understand working memory's role in learning during secondary school and how schools can support the healthy development of this crucial cognitive process. After analyzing research articles on this topic, I found critical themes within the literature that helped answer my original research questions; the pieces I focused on were the development of working memory during adolescence, the role of working memory in learning, the interplay between stress and working memory, and supporting working memory in schools. In this section, I provide recommendations to schools, teachers, administrators, and policymakers based on my research findings and personal observations as a substitute teacher. To understand the action plan that follows some general understanding of the school district and schools, I observed, is necessary.

The school district is within the borders of a mid-sized city located in the Pacific Northwest. With approximately 1,561 teachers on staff serving 28,676 students, this is Washington's largest school district (*TPS Data - Tacoma Public Schools*, n.d.). The district has 36 elementary schools, 13 middle schools, and 11 high schools (*TPS Data - Tacoma Public*

Schools, n.d.). A 2019 community needs assessment found that the percentage of youth living in poverty within the district was 35% higher than rates across Washington State and 49% higher than surrounding counties (*Community Needs Assessment - City of Tacoma*, n.d.). The economic and mental health assessments note that youth residing in South and East-end neighborhoods are at higher risk for financial instability and lower mental health scores. The community assessment also reported higher rates of economic instability, exposure to violence inside or outside the home, and consistent drug use compared to other districts in the state. Lower rates of mental wellness, a sense of personal safety, and secure housing are present in this district compared to other communities in Washington State. Despite these challenges, the district had an impressive 2022 graduation rate, with 90% of students graduating on time (*TPS Data - Tacoma Public Schools*, n.d.).

I have consistently filled in for teachers at two schools. The first is a middle school (6th, 7th, and 8th grade) with 710 total students. School demographic reports indicate the following population composition by race/ethnicity: American/Alaskan Native = 4, Asian = 104, Black = 108, Hispanic = 196, Native Hawaiian/Pacific Islander = 43, White = 133, Two or more races = 120 (*National Center for Education Statistics (NCES) Home Page, Part of the U.S. Department of Education*, n.d.) 258 students at this middle school receive free or reduced lunch rates (*National Center for Education Statistics (NCES), Part of the U.S. Department of Education*, n.d.). The high school has an enrollment of 1,376 students. The racial/ethnic composition of the high school is as follows: American/Alaskan Native = 9, Black = 214, Asian 218, Hispanic = 393, Native Hawaiian/Pacific Islander = 99, White = 267, two or more races = 164 (*National Center for Education Statistics (NCES), Part of the U.S. Department of Education*, n.d.). At the high school, 684 students receive free or reduced lunch rates (*National Center for Education Statistics (NCES), Part of the U.S. Department of Education*, n.d.). Both schools primarily serve students in the district's East and South-end neighborhoods.

The following section summarizes recommendations for supporting working memory in schools based on empirical findings from the literature and my observations at the middle and high school sites. The following action plan outlines my recommendations for building on existing classroom, district, state, and federal support structures for working memory development.

Specialized Education for Students with Working Memory Difficulties

This section addresses secondary school teachers on the importance of early detection and intervention for students with working memory difficulties. Research in this area points out the intrinsic link between working memory and other executive functions and how these processes allow students to navigate everyday school scenarios successfully. However, evidence supports the idea that many teachers need more awareness of the early indicators of working memory differences. Research recommendations in this area are helpful to consider in cooperation with the multi-tiered level of support model. My recommendations summarize how students with working memory difficulties should be identified through behavior and assessed by specialists to meet the criteria for receiving specialized education in schools. This section addresses empirical evidence about the validity of standardized working memory and behavioral-based assessments. My recommendations provide information about the type of data educators can collect to nominate students for a higher tier of support during the day and assist in monitoring the progress of individualized education plans for these students.

Table 1

Screening for Working Memory Difficulties in Schools

Research	**Practice**	**Recommendation**
Behaviors associated with working memory difficulties are distinct and can be identified by teachers observing adolescents in everyday classroom situations. Behavioral evaluations of working memory ability are suggested over direct assessments of working memory (backward digit span task or automated WM assessments) in educational settings because explicit evaluations may not accurately portray a student's working memory abilities in real-life scenarios. (Alloway, 2012; Tanock, 2014).	Teachers in the school district do not employ in-class behavioral screening for working memory or other executive functions. Students in middle school following a behavioral IEP will often ask teachers to fill out a form at the end of class that asks about behaviors associated with working memory deficits (On task behaviors, preparedness). Still, this data tracks social development, not specific executive functions like working memory.	Teachers should begin recording data on students if they notice consistent displays of working memory difficulties like forgetting the task at hand, submitting incomplete work, trouble coping with complex mental tasks, etc. If these behaviors interfere with academic or social and emotional development, teachers should consider small group interventions or referral to learning disability specialists. While professional development would assist teachers in understanding the link between behaviors and associated cognitive processes, this is optional for a teacher to begin recording data.
There is no evidence that working memory difficulties improve with age without intervention (Allen et al. l, 2013; Blankenship et al., 2015; Bull & Lee, 2016).	The only memory interventions witnessed in middle and high school were in specialized education classrooms and remedial math and reading classrooms. Memory interventions were not seen in general education classrooms.	Support for students with memory difficulties should be extended to general education classrooms. Administrators should provide professional development opportunities to general education teachers. This training should be specific to executive functions and their role in everyday classroom functioning, memory strategies, and error-free learning.
Research has shown that	Full-scale IQ tests, such as	Because working memory

individuals with higher working memory capacity tend to perform better on IQ tests and other measures of cognitive ability. Working memory capacity is a strong predictor of IQ, even after controlling for other factors such as age, education, and socioeconomic status. Researchers have developed programs to enhance working memory skills; participants who completed these training programs showed improved working memory capacity and IQ scores. (Bharadwaj et al., 2022; Robison & Brewer, 2022)	the WISC, are used to determine a student's eligibility for specialized education in school. The WISC has a subsection that directly assesses working memory capacity. A student who scores below 69 on an IQ test may qualify under one of the following disability categories: intellectual disability, specific learning disability, or other neurological disorder.	capacity predicts IQ scores the current evaluation method for receiving specialized education does work to identify students with working memory deficits after they have displayed academic or social delays. If a student has an Individualized Education Plan targeting working memory, IQ data may be helpful for teachers to report progress.

Supporting Working Memory in Classrooms

This section addresses working memory difficulties at the classroom level. My recommendations are based on developmentally appropriate instructional strategies and learning methods that support working memory. The findings cited in the table below explain the effectiveness of different approaches to mitigating the effects of working memory difficulties in schools including compensatory memory strategies, classroom environment, and instructional practices. The recommendations below call for educational opportunities for teachers facilitated by professionals in error-free learning, memory strategies, and executive functioning.

Table 2

Supporting Working Memory in The Classroom

Research	**Practice**	**Recommendation**

At the onset of puberty adolescents have developed the working memory capacity of adults, yet they are more sensitive to cognitive load; learning environments that minimize external (ex., Loud music, noise from the hallway) and internal (ex. Rumination, test anxiety) distractions are ideal for encoding new information, retaining prior knowledge, and retrieving information from long-term memory stores (Hitch, 1988; Master et al.,2020; Tamnes et al., 2013).	Many middle and high school teachers attempt to reduce cognitive load by manipulating the classroom environment. Some examples are reducing emotional distractions by creating a calming environment without overhead lighting and flexible seating arrangements. Other teachers reduce clutter in the classroom and try to minimize outside interruptions. Some post stepwise instructions for every student to see and repeat instructions throughout lessons or physically demonstrate instructions.	In addition to the actions already in practice some other steps teachers can make to reduce cognitive load are: 1. Only give students the information they need, instructions, and explanations. 2. Make instructions and expectations clear with 3. visual and verbal reminders. 4. Provide students more time between tasks so they are timely to complete. them 5. Introduce internal and external memory strategies. 6. Implement Holistic approaches, such as available social and emotional learning instruction.
Compensatory strategies appear to achieve far-transfer benefits on working memory and other executive functions like, attention control, inhibition, and emotional regulation. These strategies are most effectively taught in error-free learning environments with multiple opportunities to practice strategies in different academic settings. (Hitchcock & Westwell, 2019; Llinares, 2021)	Many classrooms in the middle school provide external memory tools for students, such as visual and verbal reminders about the bell schedule, weekly/monthly schedule, upcoming assignments, due dates, arrows for hallway directions, and step wise instructions. These types of support noticeably decline as students transition to upper-level classrooms. Internal memory methods were rarely employed outside English language learning classrooms, remedial classes, or another	Teachers should implement memory strategy training in various task-specific situations using the error-free instruction model. This type of instruction can be accomplished in small groups with select students or class-wide. Internal memory strategies (ex. mnemonics, word palace, rhymes) and external strategies (ex. calendars, digital tools, planners) are both tools that should be scaffolded with the help of immediate teacher feedback. The most effective strategies appear to be self-

	specialized education classroom.	generated by students (ex. original rhymes, or poems significant to the student's life experience). Highschool teachers should consider reinforcing memory strategies in the upper grade levels instead of a gradual reduction in support.
Studies have found that individuals with higher levels of test anxiety tend to have lower working memory capacity. This may be because test anxiety can cause cognitive interference and distract from the task at hand, leading to difficulties in retaining and manipulating information in working memory. This may lead to impaired performance on tasks that require the use of working memory. Some studies have found that interventions designed to reduce test anxiety can also improve working memory performance. (Bauman & Melnyk, 1994; Quervain et al., 2000; Schäfer et al., 2018; Sharot & Phelps, 2004)	Strategies I have seen used in classrooms are both sites include Meditation before high stakes exam, practices test broken down into smaller assignments like quizzes, study groups, ample review material, explanations about the importance of sleep before tests and exams, memory strategies like chunking and visualizing memory cues.	Other strategies teachers can use to mitigate the effects of anxiety on Working memory: 1. Practice: Engage in activities that require working memory, such as memory games, puzzles, and brain training exercises. Have students take practice exams like high stakes exams. 2. Relaxation techniques: Engage in relaxation techniques such as deep breathing, meditation, or progressive muscle relaxation to reduce feelings of anxiety and stress that can interfere with working memory performance. 3. Time management: Properly manage time before and during exams to avoid feeling rushed or overwhelmed, which can trigger test anxiety and interfere with working memory performance.

		4. Positive self-talk: Use positive affirmations and self-talk to boost confidence and reduce feelings of anxiety. This can help to improve performance on cognitive tasks and enhance working memory capacity.

Holistic Support for Working memory Development in Schools

Working memory and social-emotional learning (SEL) are interconnected, in my research I found several ways in which Working memory can impact the development of SEL skills in students. Firstly, working memory is crucial for self-regulation, which is a key component of SEL. Self-regulation involves managing one's thoughts, emotions, and behaviors in a way that promotes well-being, positive relationships, and achievement. Working memory helps students hold information in their minds and use it to guide their decision-making and behavior. Secondly, working memory is important for perspective-taking, which is another core skill in SEL. Perspective-taking involves understanding and considering other people's thoughts, feelings, and perspectives. Working memory helps students hold multiple pieces of information in their minds, which can aid in perspective-taking by allowing students to consider different viewpoints simultaneously. Thirdly, working memory is crucial for academic success, and academic achievement is closely tied to SEL. Students with stronger working memory skills are more likely to succeed academically, which can lead to greater confidence, motivation, and a sense of accomplishment – all of which are important components of SEL.

SEL initiatives and Whole Child teaching strategies became more accessible to schools following the American Rescue Plan (ARP), a federal grant intended to assist schools in reopening after the Covid-19 Pandemic. Under section 2001 of the ARP, The Elementary and Secondary School Emergency Fund (ESSER) allocated 189.5 billion dollars to schools nationwide. The district I focus on allocated $300,000 of ESSER funding to support the Character Strong SEL Program launch. Washington State received $2,991,421,126 from the ESSER; $902,053,513 is used in high schools (*Washington-State-ARP-ESSER-State-Plan-Approved-11-24-2021.Pdf*, n.d.). The ESSER reserved a portion of funding for training educators and administrators on a federal program called the Whole Child Initiative. Whole Child Practices have been adopted by my research district and focus on

The table below outlines how some of this funding was used to create a reentry plan following the COVID-19 pandemic for students' social and emotional well-being. The following table summarizes holistic approaches to improving working memory, including Universal Social and Emotional Learning Programs in schools, Positive Behavior Interventions in response to behavioral concerns, and Whole Child strategies. These programs and practices can support Working memory by attending to multiple facets of a student's life at once.

Table 3

Holistic Support for Working Memory and Executive Functioning in Schools

Research	**Practice**	**Recommendation**
Evidence suggests mindfulness based SEL programs and Whole Child practices can benefit students' working memory abilities. Additionally, these programs benefit students with teacher-reported behavioral	**District** **Character Strong:** This program does not specifically target working memory. Both the middle and high school are in phase two of this District Wide SEL program	The district should provide teachers specialized education about how emotional and social regulation skills also work to support students' working memory abilities. The district

problems, parasympathetic nervous system regulation, and executive functioning. Evidence suggests that teachers, rather than outside experts, are the most effective at implementing Holistic/SEL programs in schools. (Frank et al., 2021; Lam & Seiden, 2019)	roll-out; during this phase students at the middle and high school site receive around 45 minutes of SEL instruction once a week during their advisory period. Additionally, both schools practice the following holistic protocols for behavioral concerns and relationship building between school staff and students. **Signature Whole Child Practices:** 1. Warm greetings at the door; at the middle school site this practice is strictly adhered to, at the high school site teachers sporadically and inconsistently greet students at their classroom doors. 2. Relationship building circles; at the middle school site students engage in relationships circles for 15 minutes every Wednesday, at the high school site only students enrolled in an AVID course participate in circles. 3. Emotion checks (color zones indicating different states of emotion); this	should revise the Character Strong program in two ways, 1) include developmentally appropriate information about the basic neurological underpinnings of the co-development of cognition/executive function and emotional regulation. 2) include simple mindful practices (ex. Body scans/emotion checks) into the Whole Child curriculum more frequently throughout the school week. Teachers should not decrease adherence to Whole Child Practices as grade level increases.

	practice is frequently used at the beginning and end of classes; this practice was never seen implemented at the high school site.	
Research indicates that students with working memory difficulties are more likely to also have symptoms of anxiety and depression**;** adolescents in general are more likely to experience clinical levels of anxiety and depression than adults. Adolescents are more likely to engage in maladaptive coping strategies both internal (ex. rumination, intrusive thoughts, procrastination) and external (violence, substance use, self-harm). Delays in Social and Emotional development often accompany these symptoms and impact learning by increasing cognitive load reducing the working memory capacities of students. (Frank et al., 2021; Master et al., 2020; Quervain et al., 2000; Raffington et al., 2018; Lam & Seiden, 2019)	**Washington State SEL Benchmarks:** These skills represent adaptive thought processes that mediate the symptoms of anxiety and depression and in turn support working memory development. 1. Self-Awareness; identifying and analyzing one's emotions and behaviors. 2. Self-Management; regulating thoughts, emotions, and actions. 3. Self-Efficacy; overcoming obstacles through perseverance. 4. Social Awareness; perspective taking and empathizing with others. 5. Social Management; making safe decisions about one's personal behaviors. 6. Social engagement: willingness to participate in community activities.	Washington State SEL benchmarks align with the skills students need to optimize their memory potential. In my experience, teachers are the primary school staff administering SEL programs. For this reason, teachers need to gain a solid educational foundation in secondary students' biological and psychological development during their post-secondary teacher education. State certificating institutions and The Office of Superintendent of Schools should revise the perquisites of a secondary teaching certification from one course in Development Psychology to a more thorough course load specific to adolescents; this will help teachers deliver developmentally appropriate social and emotional instruction to meet WA State SEL Benchmarks and support working memory.
Research has shown that there is a strong association between working memory and ACE scores. ACEs (Adverse Childhood Experiences) are	ACE scores are not generally used to evaluate or suggest a student's working memory ability outside of medical or psychiatric evaluations. The	ACE scores are sensitive and personal information and should be kept confidential to protect the privacy and dignity of students and their

traumatic experiences that occur during childhood, such as physical, emotional, or sexual abuse, neglect, or household dysfunction. Research has shown that there is a negative relationship between ACE scores and working memory capacity. That is, as ACE scores increase, working memory capacity tends to decrease. This relationship has been observed across a variety of populations. Protective factors, such as supportive relationships and positive experiences, can help to mitigate the negative effects of ACEs. (*Relationship of Childhood Abuse and Household Dysfunction to Many of the Leading Causes of Death in Adults: The Adverse Childhood Experiences (ACE) Study - ScienceDirect*, n.d.; Schäfer et al., 2018)	sites I am at do employ annual questionnaires to identify students who may be at risk for adverse childhood experiences and provide support and resources. **Positive Behavioral Interventions (PBIS):** Both the middle and high school sites try to reduce practices that may reactive trauma and decrease working memory abilities by adhering to the following behavioral intervention protocol. 1. Tier 1 restorative approach to conflict and behavioral intervention. 2. Tier 2 small social skills groups, student monitoring (district examples of data for screening: office referrals, teacher nomination, formative assessments). 3. Tier 3 Direct individualized support with specialized education professional. The following funding goes towards protective factors that mitigate the effects of ACEs on working memory and overall cognition: 4. **Washington Legislator:** allocated $12,885,000 from the Elementary and Secondary School	families. I do not recommend schools screen for ACEs because they are limiting to a student's actual Working memory abilities and strengths. Instead, I suggest the following: 1. State policy should promote teaching and learning environments that integrate the goals of social and emotional success. A process that enables school communities and state agencies to implement this plan should be established. 2. Policymakers should evaluate school behavior and safety initiatives to ensure they align with trauma-informed principles. 3. Support for locally based school programs should be prioritized. School communities should be provided with the necessary resources to explore the community's requirements, including the school's capacity to implement changes in its culture.

	Emergency Relief (ESSER) III funds, provided by the American Rescue Plan Act of 2021, for the purpose of awarding grants to community-based organizations (CBOs) that will collaborate with school districts in Washington State to aid in the recovery and acceleration of learning. 5. **Federal:** American Rescue Plan Act of 2021 (ARP) has allocated $800 million to support homeless children and youth. This has been made possible through the ARP Elementary and Secondary School Emergency Relief – Homeless Children and Youth (ARP-HCY) Fund. The grant funds have been distributed to local districts based on a formula provided by the US Department of Education to help identify, enroll, retain and promote educational success for homeless children and youth. Additionally, various resources have been made available to provide districts with	

	guidance, best practices, and ideas to effectively utilize these funds.	

Summary

This section proposed a range of recommendations that educational institutions can implement to effectively support the development of working memory in secondary school settings. The discussion centers on how teachers can adopt instructional strategies that consider the limitations of working memory. Specifically, strategies such as breaking down complex tasks into smaller, more manageable steps, providing explicit instructions, and utilizing visual aids are emphasized as means of facilitating comprehension and understanding. Additionally, incorporating frequent checks for understanding, offering opportunities for practice and reinforcement, and creating a classroom environment that minimizes distractions and ensures clear organization of materials and resources are recommended to promote working memory development. Furthermore, the establishment of consistent routines and procedures is highlighted as a method of reducing the cognitive load placed on working memory.

Recognizing the individual differences in working memory capacities among students, the implementation of differentiated instruction is advocated to address diverse needs. This involves providing additional support or scaffolding for students with weaker working memory skills, while offering enrichment opportunities for those with stronger capabilities. Moreover, teaching students' specific strategies to enhance their working memory, such as mnemonic techniques like visualization or chunking, and the use of external memory aids like note-taking, concept mapping, or adaptive technology, is suggested to alleviate the demands on working memory. Access to tools and applications that provide visual organizers, reminders, or note-taking capabilities is also proposed as a valuable resource for assisting students in organizing and retaining information.

To enhance educators' understanding of working memory and its impact on learning, the provision of professional development opportunities is recommended. Collaborative efforts among teachers can facilitate the sharing of best practices and strategies for supporting students with working memory difficulties. Additionally, collaboration between general education teachers and specialized educational support professionals can facilitate behavioral assessments, targeted interventions, and the development of individualized strategies and accommodations.

Finally, the integration of Social-Emotional Learning (SEL) programs, Positive Behavioral Interventions (PBIs), trauma-informed safety and discipline protocols, and Whole Child Practices is presented as a comprehensive approach to promoting working memory development. These initiatives aim to foster self-awareness, self-regulation, mindfulness, collaboration, goal setting, problem-solving, resilience, and positive relationships, ultimately enhancing students' working memory capabilities and overall academic success. By implementing these various supports, educational institutions can create a conducive learning environment that acknowledges and nurtures the development of working memory, thereby enabling students to effectively engage in complex cognitive tasks and achieve academic excellence. In conclusion, it is emphasized that the recommendations provided are tailored to the recognition that individual students possess diverse strengths and weaknesses in working memory, necessitating personalized support, ongoing assessment, and feedback to monitor their progress effectively.

Discussion

As a substitute teacher, I often observe students struggling to remember tasks or instructions throughout the day and wonder how much of their learning is impacted by these negligible but consistent interferences. I set about this research in search of actionable steps to aid students with memory difficulties in the classroom. I searched for realistic strategies that could work in various settings with students that I had yet to develop a student-teacher relationship with. What I found was that holistic practices that attend to students' social and emotional well-being also support Working memory development. This section synthesizes my literature and research site findings to answer my original questions. Then I summarize these findings' implications on teachers, schools, and governing bodies. Next, I will describe gaps I found in the literature to be filled by future scientific investigations. I discuss this project's limitations and, finally, end with a conclusion of my understanding of the importance of Working memory in schools.

Discussion of Findings

The focal questions of this research project were: 1. How does working memory typically develop during adolescence? What role does working memory play in learning during adolescence? How does stress influence working memory processes in secondary students? How can secondary schools support working memory development? This section discusses the answers to this project's guiding questions. Then I speculate on the future trends of working memory in educational research and secondary schools. Next, I analyze trends in the methodological paradigms of working memory research. literature to discuss changes in the scientific understanding of working memory over time.

Working Memory Development

Working memory typically improves during adolescence. This is due to a combination of factors, including brain maturation, increased experience with cognitive tasks, and improved strategies for managing cognitive demands. Research suggests significant improvements in working memory capacity, speed, and accuracy during adolescence, particularly between the ages of 10 and 15. This finding was discussed by Master et al. (2022) during their cross-sectional analysis of working memory development in relation to puberty-related hormonal changes. Additional findings in this area suggest that 8–12-year-olds suffer more from high cognitive loads, and modest working memory changes can be seen during the ages of 13-17, with the largest gains seen at the onset of puberty. These improvements are linked to changes in the prefrontal cortex, a brain region critical for working memory and other executive functions. This finding was demonstrated by Tamnes et al. (2013), in their groundbreaking longitudinal MRI investigation of structural brain maturation in relation to working memory abilities.

Evidence suggests that individual differences, such as genetics, environmental factors, prior experiences, and mental health, may influence working memory development. For example, Malagoli & Usai (2018) illustrated the co-development of emotional regulation and working memory, noting that adolescence with poor emotional regulation skills also tend to have weaker working memory performances. The researchers also noted that adolescents are particularly vulnerable to depression and anxiety symptomology, increasing the demand for working memory processes. There is strong evidence that the development of working memory plays a role in the maturation of other higher-order cognitive functions involved in regulating one's emotions, suggesting that interventions targeting working memory may benefit other cognitive skills.

Secondary teachers at both research sites seemed generally familiar with working memory and its importance in learning and cognitive development. Fewer teachers were familiar with the connection between emotional and social development and working memory development. The depth of knowledge and understanding about working memory development varied among individual teachers based on their training, experience, and ongoing professional development opportunities. Some teachers had more specialized knowledge in cognitive psychology or learning disabilities, while others may have a broader understanding of working memory and its implications for teaching and learning. Teachers were familiar with the idea that working memory develops and improves over time; they understood that working memory capacity tends to increase throughout childhood and adolescence, but individual differences exist.

Teachers at both sites often adjusted their instructional practices and support strategies based on their student's grade levels and developmental stages. Here is an example of how teachers adapted instructions to support working memory development by grade: In Middle School (Grades 6-8), teachers provided more explicit instruction and note-taking strategies such as Cornell notes or graphic organizers. These techniques help students organize and summarize information, aiding in working memory management. Whereas in High School (9-12) teachers transitioned to more metacognitive strategies, including self-awareness of their working memory strengths and weaknesses. Students learned to monitor their own cognitive processes, identify memory challenges, and employ appropriate compensatory strategies.

In all grade levels, teachers emphasize the importance of a supportive and organized classroom environment. Teachers established clear routines, provided consistent expectations, and offered positive reinforcement. Teachers also collaborated with other professionals, such as special education teachers or school psychologists, to address specific working memory difficulties that students may have. While these adaptations serve as general guidelines, it's essential for teachers at both sites to consider the unique needs of their students with working memory difficulties and adjust their instructional approaches accordingly.

The Role of Working Memory in Learning During Adolescence

Working memory is critical for learning during adolescence. It enables adolescents to hold information in mind while processing and integrating it with new information, allowing them to reason, problem-solve, and make decisions based on multiple sources of information (Alloway & Alloway, 2010). Research has shown that individuals with higher working memory capacity tend to have higher IQ scores, and working memory capacity strongly predicts academic achievement in children and adults (Alloway & Alloway, 2010).

Studies have specifically examined the role of visual-spatial working memory in secondary students' mathematical achievement. A systematic review by Allen et al. (2019) found evidence supporting the positive association between visual-spatial working memory and math performance, particularly in tasks involving manipulating visual-spatial information, such as geometry and problem-solving tasks. Memory updating and recollection processes have also been found to play a crucial role in cognition and academic achievement in secondary school students. Bull & Lee (2016) demonstrated that memory updating is essential for tasks requiring continuous updating and monitoring, such as mental arithmetic and reading comprehension.

Blankenship et al. (2015) highlighted the importance of recollection in tasks requiring previously learned information, such as reading comprehension and problem-solving.

Teachers at both sites seemed to understand that universal support strategies can alleviate the frustration felt by students with working memory difficulties. Without explicitly recognizing the role of working memory, secondary teachers made informed instructional decisions that provided appropriate support to help students overcome these challenges. Teachers designed activities and assignments that foster critical thinking and problem-solving skills. Teachers guided study skill sessions and demonstrated test-taking strategies. Techniques such as active reading, summarizing, mnemonic devices, and practice tests were seen more so in the middle grades and can work to support students' memory retrieval during exams.

The Influence of Stress on Working Memory

When I started this research, I aimed to understand all the factors that influence the working memory abilities of secondary students. This is a short list of the factors that may influence working memory: age, genetics, environment, education, motivation and attention, nutrition, physical exercise, and technology use. Given that community youth health surveys indicated my site had high rates of exposure to adverse childhood events, such as economic instability, violence, and abuse in the home I limited my focus to how chronic and acute stress may impact a student’s working memory performance.

The study of the captive Capuchin Monkey population Sosnowski et al., (2022) provided strong evidence that a biological underpinning may determine individual differences in working memory performances on high-stakes assessments. Quervain et al., (2000) described how when a person experiences acute stress, their body releases cortisol, a hormone that can impair declarative memory retrieval and working memory. Their findings also suggested that when information is first taught, individuals may benefit from low levels of stress. Rydell (2009), addressed how stress associated with stereotype threat in educational settings may impair working memory abilities. Hawkins et al., (2021) provided comprehensive evidence suggesting that the more adverse childhood experiences an individual is exposed to, the lower their working memory performances are. Raffington et al., (2018) described how students who experience chronic stress, such as those from low-income or disadvantaged backgrounds, may have lower working memory capacity and struggle academically.

It's important to note that not all stress is bad, and not every person exposed to an ACE will experience negative effects on their memory. Raffington et al., (2018) and Hawkins et al., (2021) highlight strong evidence that positive adult relationships can help mitigate the negative effects of ACEs on students' cognitive functioning. Variables such as mental health, social support, and community engagement can also moderate the impact of chronic stressors on a student's physiological stress response. Moderate stress levels can enhance cognitive function and improve working memory performance, but only up to a certain point. Stress can negatively affect working memory and other cognitive processes when it becomes chronic and overwhelming.

I observed ongoing flexibility on behalf of teachers at my research site in their efforts to reduce different stressors in the classroom. The findings of Rydell et al., (2009) have several implications for educational settings. For instance, the study suggests that individuals with multiple social identities may be particularly vulnerable to stereotype threats, which can negatively impact their working memory and cognitive performance. Therefore, creating inclusive and supportive environments that acknowledge and value the diversity of individuals' social identities is important. and coping mechanisms, so it's important to adapt strategies to meet their individual needs. Teachers at my research site are regularly enrolled in equity training to create a supportive classroom culture. Teachers at both sites seem adept at fostering a classroom environment that promotes kindness, empathy, and respect. I observed teachers encouraging this environment through collaborative assignments that required teamwork which built positive relationships among students. This helped to create a supportive network that can alleviate stress.

Additionally, I observed teachers modeling healthy stress management techniques like deep breathing and brain breaks at the middle school sites. I observed teachers providing individual attention when needed, offering guidance, encouragement, and support to students struggling academically or emotionally. Teachers regularly recognized students’ efforts and celebrated their achievements. Other teachers curated a calming classroom with soft lighting, calming colors, and comfortable seating. Some classrooms fostered open communication by using anonymous suggestion boxes, actively listening to students, validating their feelings, and addressing their concerns promptly.

School Support for Working Memory Development

Working memory problems are prevalent in students and can impact academic achievement. There is strong evidence that schools can support students with working memory difficulties by implementing these strategies: compensatory memory strategies, differentiation for cognitive load in the classroom, behavioral screening, holistic strategies, and error-free instructional styles are effective methods to support students with working memory difficulties.

This section discusses the alignment between how my research site supports working memory development and the findings drawn from the literature.

Compensatory Strategies. Compensatory memory strategies are techniques or approaches that individuals can use to help overcome or work around difficulties with their memory. These strategies aim to enhance memory performance using external aids, organization techniques, or specific cognitive processes. Research suggests that individuals may need to experiment with different techniques to find the best. Pizzania and Suhr (2022) conducted a double-blind controlled trial, and Oneil-Porozzi et al. (2010) conducted a comprehensive literature review, contributing to the body of research highlighting the positive impact of compensatory memory strategies on working memory performance. These strategies encompass various techniques, such as visual aids, repetition, chunking, and association. The findings suggest that teachers can play a pivotal role in assisting students in developing these strategies to enhance their working memory and academic achievement. Additionally, Evans et al. (2000) and Wilson & Evans (1996) provide compelling evidence supporting the effectiveness of errorless teaching strategies, particularly for teaching memory strategies to secondary students experiencing working memory difficulties.

In the context of my research sites, implementing errorless teaching techniques was commonly observed in special education settings aimed at teaching new skills to students, especially those with learning difficulties or disabilities. Although less prevalent in regular classrooms, teachers still adapted and incorporated elements of errorless teaching to support their students. Notable strategies observed included task analyzing, which involves breaking down complex skills or tasks into smaller, clearly defined steps sequenced logically. Additionally, teachers provided explicit instructions using straightforward language, modeled correct responses through step-by-step demonstrations, offered prompts and cues for guidance, provided immediate feedback by reinforcing correct answers and gently correcting errors, and employed repetition and reinforcement to enhance the retention of skills or tasks.

Interestingly, teachers instructing older grades exhibited a lower utilization of compensatory memory strategies in their classrooms, despite the higher cognitive demands placed on these students. The most prevalent memory strategies observed were external in nature, with students utilizing school-provided laptops to access course documents, schedules, and to-do lists. An area for growth in teaching compensatory memory strategies and errorless instruction at these sites lies in fostering generalization. This entails facilitating the application of newly acquired memory strategies or skills across diverse situations and settings, enabling students to transfer their knowledge to real-life scenarios or related tasks.

Overall, teachers at both research sites displayed commendable levels of patience and persistence, as these qualities are integral to effective errorless teaching. They demonstrated an understanding that students may require additional time to grasp concepts or skills and maintained a positive and supportive attitude, emphasizing progress and growth rather than expecting perfection.

Behavioral Screening. Behavioral screening is emerging as a useful tool for identifying working memory difficulties in schools. While working memory assessments typically involve more comprehensive cognitive tests administered by professionals, behavioral screening can help identify students who may be at risk for working memory difficulties and require further evaluation. Some approaches and strategies for behavior screening in schools identified in the literature were: teacher observation, checklist or rating Scales, academic performance and work samples informal conversations and interviews, and behavior rating systems.

Normand and Tannock's (2014) and Alloway's (2012) empirical studies provide evidence suggesting that behavioral rating scales can serve as reliable alternatives to direct assessments when evaluating working memory. In the context of working memory assessment, behavioral screening encompasses the observation of students' behavior and the completion of questionnaires to identify individuals experiencing challenges with their working memory abilities. The implementation of behavioral screening in educational settings holds significant value, as it aids in the identification of students requiring additional support. Regrettably, during my research at the selected sites, behavioral screening was not utilized as a means of assessing working memory ability within the classroom environment.

Nonetheless, it is important to note that students enrolled in behavioral Individualized Education Programs (IEPs) at the middle school did undergo daily behavioral surveys, which were completed by each teacher. These surveys entailed teacher ratings of students on a four-point scale, encompassing preparedness, task completion, peer interaction, and class disruptions. This practice exemplifies the teachers' existing proficiency in deploying such assessments within the classroom setting, both for screening purposes and the generation of student progression reports.

Working Memory Training. There is growing evidence that specific working memory train programs may improve working memory capacity. Hitchcoack & Westwell (2017) discuss their findings following an evaluative investigation of a CogMed working memory training program by saying that more research is needed to understand how direct memory training is implemented to insure positive memory results. There is not enough evidence yet to say if direct working memory training could benefit students in schools.

Cognitive Load Theory. Cognitive Load Theory is a framework that explains how the capacity of working memory influences learning and information processing; it suggests there are limitations to the amount of new information that learners can process effectively at a given time. Merriendoer & Pass (2020) suggested that according to Cognitive Load Theory, working memory has a limited capacity for processing information. Merriendoer & Pass (2020) described how the Cognitive Load Theory could be applied in the classroom to enhance memory abilities. Simplifying language, chunking information, using visuals, scaffolding learning, using repetition, and reducing distractions effectively reduce cognitive demand for students with memory difficulties. Llinares et al., (2021) offered experimental evidence that classroom color choice may influence students' cognitive abilities, specifically working memory. This study provides an example of an environmental differentiation that reduces cognitive load by regulating a student's nervous system allowing students to maintain attention on the task. Research is still growing, and it is unclear what specific colors, lighting, or noises influence a student's cognitive load.

Strategies such as decluttering the classroom environment and minimizing external distractions have been proposed to reduce cognitive load within educational settings. However, the consistent implementation of these practices was lacking among educators at both sites under investigation. Several teachers at both sites employed deep breathing techniques with their students prior to significant assessments, aiming to mitigate the cognitive load induced by classroom stressors. Additionally, many teachers adopted open note assessments, which alleviate the cognitive burden of retrieving information from long-term memory reserves. Both sites incorporated regular review sessions and reinforcement activities, such as educational games, to reinforce previously acquired knowledge. Visual aids and graphic organizers were employed at both sites to facilitate students' comprehension of intricate concepts by providing visual representations of relationships and connections. Moreover, teachers at both sites utilized scaffolding techniques, progressively increasing the complexity and challenge of learning tasks while offering appropriate support and guidance through prompts, cues, and modeling.

Despite these commendable practices, prioritizing essential content is an area for improvement in both sites' classrooms. Teachers can avoid inundating students with excessive details that may overload their cognitive capacities by focusing on pivotal and contextually relevant information. Multimodal instruction emerged as a particularly robust technique for reducing cognitive load, as educators at both sites adeptly engaged students through various sensory modalities, encompassing visual aids, hands-on activities, group discussions, and technological resources. Unbeknownst to the teachers, regular breaks during the school day were also instrumental in reducing cognitive load, affording students opportunities to process information and replenish their cognitive resources. By integrating breaks into extended tasks or breaking down lessons into shorter segments, educators successfully mitigated cognitive fatigue among students.

Holistic Strategies. Comprehensive meta-analysis and independent SEL program evaluations show that holistic strategies can help students to be more motivated, focused, and engaged in learning and show improved working memory functioning (Jha et al., 2019). Examples of holistic strategies include mindful practices, Whole Child Practices, and adequate sleep. More research is needed in this area to understand how to motivate students to practice and adhere to SEL programs in schools, however overall, these programs tend to have a positive impact on working memory (Jha et al., 2019). Fostering healthy adult-child relationships and community engagement also appear to support working memory development (Hawkins et. al, 2021).

Numerous educators at the secondary level, particularly in high schools, demonstrated limited adherence to the district-wide initiative known as Whole Child Practices. Despite the recognized benefits of nurturing supportive relationships between adults and students, many high school teachers neglected key components of this initiative. These included failing to greet students at the door, neglecting to employ color zones to assess students' emotional well-being and infrequent participation in relationship-building circles. In contrast, middle school students were consistently exposed to these practices, albeit with limited enthusiasm for the emotional zone and relationship-building circle activities.

A lack of contextualization and generalization hindered the effectiveness of the Character Strong Social-Emotional Learning (SEL) program during instruction. This program covered various SEL competencies: self-awareness, self-management, social awareness, relationship skills, and responsible decision-making. However, the program failed to establish a clear connection between these competencies and their practical application in diverse contexts. Consequently, students appeared perplexed regarding the purpose and potential benefits of completing the program. The teacher responsible for implementing the program and the students receiving the intervention did not possess an inherent understanding of the link between the development of SEL competencies and overall cognitive growth.

Moving forward, the district should address several barriers to success. These include securing buy-in from teachers and students, providing greater clarity in program objectives, assessing the school's readiness for change, and offering professional development opportunities focused on adolescents' social, emotional, and cognitive development. By addressing these challenges, the district can foster a more conducive environment for successfully implementing holistic initiatives that support working memory.

Methodological Paradigms in Working Memory Research

Working memory research utilizes various methodological paradigms to investigate its functioning and implications. Experimental paradigms within working memory research involve manipulating independent variables and measuring their effects on working memory performance. These paradigms often use controlled laboratory settings and standardized tasks to isolate specific aspects of working memory and examine their influence. Researchers can uncover the underlying mechanisms of working memory and how it interacts with other cognitive processes by manipulating variables such as load, presentation format, or interference. The implications of experimental paradigms include providing insights into the cognitive processes involved in working memory, identifying factors that affect working memory performance, and informing the development of interventions and strategies to improve working memory capacity.

Dual-task paradigms involve simultaneously performing two tasks that require working memory resources. These paradigms aim to understand the limitations and capacity of working memory by examining the performance trade-offs when multiple tasks compete for the same cognitive resources. Researchers can gain insights into the capacity limits of working memory and its role in multitasking by investigating the dual-task interference effects. The implications of dual-task paradigms include understanding the constraints of working memory in real-world situations, informing educational practices that involve multitasking, and highlighting the challenges students may face when managing multiple cognitive demands.

Neuroimaging paradigms like functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) allow researchers to examine the neural correlates and brain networks associated with working memory processes. These paradigms provide a window into the brain regions and activation patterns involved in working memory tasks. They offer insights into the neural mechanisms underlying working memory capacity, the relationship between working memory and other cognitive functions, and the impact of individual differences in brain activity on working memory performance. The implications of neuroimaging paradigms include advancing our understanding of the neural basis of working memory, facilitating the diagnosis and treatment of working memory deficits, and guiding the development of brain-based interventions.

Longitudinal studies follow individuals over an extended period, tracking their working memory performance and changes over time. These studies examine the developmental trajectory of working memory from childhood to adolescence and adulthood, providing insights into the growth and stability of working memory capacity. Longitudinal studies also help identify the predictive relationship between working memory and academic achievement, cognitive development, and real-world outcomes. The implications of longitudinal studies include informing educational policies and interventions that aim to support working memory development, identifying critical periods for working memory interventions, and understanding the long-term implications of working memory on educational and cognitive outcomes.

Individual differences paradigms focus on understanding the variations in working memory capacity among individuals. These paradigms examine the influence of factors such as age, cognitive abilities, educational background, and genetic factors on working memory performance. By exploring individual differences, researchers can identify factors that contribute to working memory strengths and weaknesses, assess the impact of working memory on learning outcomes, and develop personalized interventions. The implications of individual differences paradigms include promoting educational practices that accommodate diverse working memory capacities, identifying students who may benefit from targeted interventions, and tailoring instructional strategies to support students with different working memory profiles.

The methodological paradigms used in working memory research, such as experimental paradigms, dual-task paradigms, neuroimaging paradigms, longitudinal studies, and individual differences paradigms, provide valuable insights into the functioning of working memory and its implications. These paradigms help uncover the underlying mechanisms, capacity limits, neural correlates, developmental trajectories, and individual variations in working memory, ultimately informing educational practices, interventions, and strategies to support students' cognitive abilities.

In terms of the conceptualization of memory, methodological paradigms in working memory research exhibit divisions that revolve around how memory is understood and defined. These divisions primarily stem from two contrasting viewpoints, a storage-based perspective, and a processing-based perspective. Paradigms aligned with a storage-based perspective view working memory as primarily concerned with the passive storage and maintenance of information. According to this viewpoint, working memory acts as a temporary storage system where information is temporarily held before being either forgotten or transferred to long-term memory. This perspective often emphasizes the capacity limits of working memory and the role of attention in selecting and encoding relevant information. In contrast, paradigms aligned with a processing-based perspective conceptualize working memory as an active cognitive system that involves not only the storage but also the manipulation and processing of information. From this viewpoint, working memory is seen as a dynamic workspace that supports ongoing cognitive processes, such as reasoning, problem-solving, and decision-making. This perspective emphasizes the role of executive functions and the flexible allocation of attention to different working memory representations.

The division between these perspectives reflects differing conceptualizations of the underlying mechanisms and functions of working memory. While storage-based perspectives highlight the role of temporary information maintenance, processing-based perspectives emphasize the active manipulation and transformation of information within working memory. These differing conceptualizations also influence the choice of experimental tasks used in working memory research. Paradigms aligned with a storage-based perspective often utilize tasks that assess the capacity limits of working memory, such as digit or spatial span tasks. In contrast, paradigms aligned with a processing-based perspective may employ tasks that require the updating, manipulation, or integration of information, such as n-back tasks or complex span tasks.

It is worth noting that while there is a division between these perspectives, there is also recognition of the interplay between storage and processing aspects of working memory. Many contemporary models of working memory, such as Baddeley's model incorporate both storage and processing components, acknowledging their intertwined nature. The conceptualization of memory in methodological paradigms within working memory research reflects divisions between storage-based and processing-based perspectives. These divisions shape the theoretical frameworks, choice of tasks, and research questions explored in the field, contributing to a rich and multifaceted understanding of working memory.

Limitations of Research on Working Memory

Working memory research in the field of education has made significant contributions to our understanding of how secondary students acquire, process, and retain information. However, it is important to consider the limitations specific to working memory research in this population. Firstly, limited representation is a common limitation of research in this area. Many studies on working memory in education involving secondary students rely on small sample sizes and controlled laboratory settings. These conditions may not fully capture the complexities and diversity of real-world classroom environments experienced by secondary students. Consequently, generalizing findings to different educational contexts and diverse student populations can be challenging.

Ecological validity limits what we know about working memory from the current research. The tasks used to assess working memory in research studies may not accurately reflect the cognitive demands encountered by secondary students in their daily academic activities. The artificial nature of these tasks may fail to capture the dynamic and multifaceted nature of working memory in real classroom settings. Therefore, caution is warranted when attempting to apply findings from laboratory settings to educational practices in secondary schools.

Measurement challenges also impact how findings from working memory investigations are interpreted. Measuring working memory in secondary students often involves standardized tests or experimental tasks. However, these measures may not fully capture the complex interplay between working memory and other cognitive processes relevant to the learning experiences of secondary students. Relying solely on such measures may limit the understanding of how working memory operates within the specific context of secondary education.

There is room for growth in understanding and appreciating individual differences in working memory capacities. Working memory capacity varies among secondary students, influenced by factors such as age, experience, and cognitive abilities. However, research on working memory in education often treats it as a uniform construct, failing to account for individual differences in this population. Neglecting these variations may limit the applicability of findings and hinder the development of tailored interventions for improving working memory in secondary students.

There is also limitation to interpreting data in on the topic of working memory and its relationship to academics. Establishing the causal relationship and directionality between working memory and academic outcomes in secondary students is complex. It is challenging to determine whether working memory deficits lead to academic difficulties or if the demands of secondary education impact the development and utilization of working memory. Investigating these relationships requires longitudinal research and advanced statistical analyses specific to the secondary student population.

Finally, the practical implications of working memory research are somewhat vague. While working memory research offers valuable insights into the cognitive processes involved in learning, translating these findings into practical strategies for educators working with secondary students is an ongoing process. Further research is needed to explore how interventions targeting working memory can be effectively implemented in real secondary school settings to enhance student learning outcomes.

In conclusion, working memory research in the field of education has contributed significantly to our understanding of how secondary students process information. However, it is important to consider the limitations specific to this population when interpreting and applying findings. Researchers and educators should be mindful of these factors to ensure that the findings are appropriately applied in secondary educational settings.

Implications for Teachers, Schools, and Governing Bodies

Teachers play a vital role in supporting working memory in Schools. Without specialized training teachers can collect behavioral data to initiate the process of supporting students with difficulties with working memory in schools and aid in data collection for students already enrolled in Individualizes Learning Plans. Though teachers do not currently use behavioral assessment screening for Working memory in the classroom, it is apparent from my findings of practice in Table 2. In my action plan that many teachers at both sites employ some of the memory-supportive strategies promoted in the literature. Practices supporting working memory were often seen at the middle school site and in remedial and specialized education classrooms. The memory strategies I recommended in Table 2. are commonly used to offer differentiated instruction for students within the classroom without the teachers' specific intent of supporting working memory. Because of this research, I think teachers should look toward implementing error-free instructional strategies for students with memory difficulties. In an errorless learning approach, information is presented gradually and incrementally so that the learner can absorb and process it before moving on to the next level. Scaffolding can occur through the guided practice of memory strategies in various scenarios, visual aids, and cues like timers and reminders, which provide the learner with the correct response or information. Errorless learning is particularly effective for learners with working memory deficits, as it allows them to focus on learning new information without the added burden of remembering what they got wrong in the past.

Teachers are also the best at achieving positive student outcomes following Social and Emotional program instruction, as opposed to outside program administrators. In my experience, teachers were almost always the instructional guides for the Character Strong SEL program. For this reason, district officials and school administrators should invest in funding that supports teachers in their ability to 1) adhere to program instructional strategies, 2) improve student motivation and engagement and, 3) create inclusive classroom environments for multiple social identities. Student participation/independent practice of SEL strategies and the administrator’s fidelity to the SEL program was pointed out as a main determinant of SEL program success in the literature. Districts also need to consider supporting teacher education in other ways too. The impact of stress on working memory can be addressed by providing teachers with information about how acute classroom stressors (stereotype threat, high stakes quizzes/tests), and chronic stressors (economic instability, parent divorce, abuse) can impair working memory performance at school. Acute stressors can dampen a student’s working memory performance, things like practice for tests, open note testing, and meditation and relaxation before a quiz can help students with working memory difficulties perform to their fullest abilities. At the state level, secondary teaching certification requirements should include a more comprehensive teacher education in the areas of adolescence social and emotional development to help them navigate stressors in the classroom and SEL program curricula with confidence.

The nation's overall approach to supporting working memory and other cognitive functions in school is leaning towards a more holistic approach, as evidenced by their allocation of SEL and community infrastructure funding. My sites and others across the state and country have revised behavioral policies that generally align with the Positive Behavioral Interventions outlined in Table 3. of the action plan. States have similarly adopted the SEL benchmarks that mirror those of Washington State, though some states continue to resist this revision to state educational standards. Professionals in the field of education and policy makers need to consider the integration of a multidisciplinary approach to supporting students. Revisions to school safety and behavior policies should be based in the latest protocols of trauma informed science. Finally, schools should continue to promote healthy teacher-student relationships as they provide a protective factor during adolescent development.

Implications for Future Research

The future of working memory research is likely to focus on several areas. One area is the development of more precise and reliable ways of measuring working memory, including using classroom screening tools and new technologies such as brain imaging and other physiological measures. For example, one commonly used working memory measure for adolescents is The Wechsler Intelligence Scale for Children (WISC); the WISC is a standardized intelligence test that includes a working memory subtest. The WISC is a validated Working memory assessment for children and adolescents between 6 and 16. The accuracy of the WISC and other direct assessments of working memory is still under debate. In the literature, I found many arguments that question whether direct working memory assessments accurately represent the working memory demands of a classroom or how a student might mitigate a memory challenge in real life. Because each study might use a different Working memory assessment, this has limited researchers' ability to approach working memory measures from a meta-analytic lens. I suspect rigorous testing of educational researchers to validate an efficient and accurate classroom screening tool based on actual academic demands and student behavior will be the focus of future research. Future educational research should focus on controlled classroom settings to understand how students navigate working memory in realistic scenarios and evaluate the practicality of strategy implementation.

Another area of interest is the investigation of the neural underpinnings of working memory, including identifying specific brain regions and networks involved in working memory processes: this may lead to the development of targeted interventions that aim to enhance working memory abilities in specific populations. A gap in the literature on Working memory was comprehensive longitudinal studies investigating working memory development. Cross-sectional analyses did provide some evidence about working memory concerning hormonal changes during adolescence, structural maturation of the brain, and emotional changes. However, more substantial longitudinal evidence is necessary for this area, particularly on typically developing student populations. The subjects of study for scientific inquiry on working memory are often populations with apparent differences in working memory processes (i.e., ADHD/ADD, ODD, ASD). Longitudinal studies on typically developing students are necessary to generalize these findings to the larger student population.

Additionally, there is growing interest in understanding the role of working memory in developing other cognitive skills, such as attention, decision-making, and problem-solving; This may lead to a better understanding of the mechanisms underlying cognitive development and the design of more effective educational interventions. Educational researchers should fill gaps in knowledge about the interplay between executive functions. This research may provide substantial evidence for Social and Emotional Learning programs which function in part to improve students' lives through supporting executive functions. Training programs specific to working memory and executive functions show promise in their ability to enhance users Working memory capacities, but more researcher is needed to understand what intensity and duration of training produces far-transfer results.

Finally, there is a growing recognition of individual differences in working memory, including genetic and environmental factors that may influence working memory abilities, this may lead to a better understanding of the factors that contribute to individual differences in cognitive abilities and the development of personalized interventions that consider these differences. As America's schools move towards the Whole Child model, they are more appreciative of the factors that influence a student's performance at school. Researchers should continue to explore how adverse childhood experiences, such as exposure to violence or financial instability, affect social and academic performance at school, specifically memory. This research looked at the impact of stress and students' memory, but there are many facets of students' life to consider, for example, mitigating factors like community relationships. The future of working memory research is likely to be a dynamic and interdisciplinary field that integrates advances in cognitive psychology, neuroscience, and educational research to improve our understanding of the role of working memory in human cognition and development.

Limitations of The Project

This project had several limitations that should be acknowledged. The research was conducted using the advanced search engine of the University of Washington Library, employing a variety of terms and phrases related to working memory in secondary schools and its implications for learning and teaching. Initially, the focus was on peer-reviewed articles written by educational researchers within the last ten years that specifically examined working memory in secondary-aged students. However, as the research progressed, the scope was expanded to include studies from cognitive neuroscience and psychology to gather a comprehensive understanding of the topic. Additional search phrases were utilized, such as "working memory training," "working memory rehabilitation," and "working memory and executive function," leading to the exploration of working memory in diverse populations, including young adults, animals, individuals with traumatic brain injuries, and neurodivergent individuals.

The expansion of the search was necessary due to the limited availability of research specifically focused on working memory in secondary-aged students and classroom-based analysis. Moreover, certain articles studying post-secondary students were included based on similarities between the working memory processes of young adults and adolescents from a developmental perspective. To ensure a comprehensive review, relevant articles older than ten years were also considered if they were foundational studies or specifically related to adolescents. Through this extensive literature review, it became evident that working memory ability is influenced by various cognitive processes and factors. The review primarily focused on factors impacting working memory outcomes, such as stress, adverse childhood experiences, social-emotional and physiological development, and individual differences. Additionally, articles examining factors that mitigate working memory difficulties, such as teacher screening and direct or holistic working memory interventions, were included. Search terms related to these topics included "stress and working memory," "working memory and cortisol," "working memory and puberty," "working memory and mindfulness," and "working memory and social-emotional learning."

In total, 31 articles published between 1988 and 2022 were included in the literature review with the majority of articles between 2000-2023.

Another limitation of this project pertains to the role of the researcher as a substitute teacher at the research sites. While this position allowed for exposure to various secondary classroom setups, teaching strategies, student-teacher relationships, and student behaviors, the observations may have lacked consistency across the different sites. The researcher's presence was limited to specific days of the week depending on the availability of substitute positions. A more consistent presence at each site might have provided a different perspective on the adherence of schools to practices such as whole-child initiatives, memory strategies, or mindfulness practices.

Conclusion

Working memory development is important for secondary school students for several reasons. Academic demands increase significantly in secondary school, with students expected to process and retain more complex information across multiple subjects. Strong working memory skills can help students meet these demands by enabling them to better process and manipulate important information enhancing their ability to learn in class, complete significant assignments, and score better on exams. Working memory development is also important for building other cognitive skills such as attention, focus, problem-solving, reasoning, and comprehension - crucial for academic and professional success. These skills can help students to remain attentive and focused on class, engage better in classroom discussions, and communicate more clearly with teachers and peers. Working memory development is crucial for a student's academic, social, and emotional growth and can promote success in various contexts.

This master's project has presented an extensive literature review encompassing diverse fields such as education, cognitive neuroscience, and psychology, and a comprehensive understanding of working memory has been attained. This project has shed light on the multifaceted nature of working memory, highlighting its crucial role in various cognitive processes and its significant impact on academic performance. The findings have underscored the limitations and challenges associated with working memory, particularly in the context of secondary school settings. Moreover, this project has provided valuable insights into effective instructional strategies and interventions that can support working memory development and mitigate working memory difficulties among secondary students.

This master's project contributes to the existing body of knowledge on working memory and provides practical implications for educators, school administrators, and policymakers. By recognizing the importance of working memory in the learning process and implementing evidence-based strategies, schools can create an inclusive and supportive educational environment that promotes optimal working memory functioning, enhances students' cognitive abilities, and ultimately fosters academic success.

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