ABSTRACT

Title of Capstone:	ACTIVATING WORKING MEMORY THROUGH ACTION AND EXPRESSION: PRACTICAL APPLICATIONS OF UNIVERSAL DESIGN FOR LEARNING TO IMPROVE MATH OUTCOMES FOR SECONDARY STUDENTS WITH SPECIFIC LEARNING DISABILITIES
	Leah Washington Zamor, Doctor of Education, 2025
Capstone directed by:	Dr. Carolyn Fink, Department of Counseling, Higher Education and Special Education

Secondary students with specific learning disabilities consistently experience significant challenges in mathematics, particularly in algebra, due in part to working memory (WM) deficits. In this capstone project, I examined how instructional practices grounded in the universal design for learning (UDL) principle of action and expression can support WM, strengthen algebraic reasoning, and reduce performance disparities. A literature review was conducted to identify predictors of algebraic success, to identify math challenges faced by students with specific learning disabilities, and to explore how the UDL could serve as an intensive instructional intervention for educators as practitioners. Empirical evidence identified predictors of algebraic success for students with specific learning disabilities if they focus on fractions as a gateway through instructional practices grounded in the action and expression principle of the UDL; the UDL can activate WM processes by reducing cognitive load, which serves as an intensive intervention to strengthen algebraic reasoning skills and reduce academic performance disparities among secondary students with disabilities. Findings informed the development of a UDL-based lesson design template (the PLAN framework) that emphasizes goal setting, cognitive load reduction, multiple means of expression, and self-monitoring. The proposed professional learning framework equips educators to integrate UDL strategies into secondary math instruction—particularly in fractions as a bridge to algebra—to activate WM processes and improve student outcomes. Actionable steps highlight the dual-year implementation of a universally designed instructional intervention for educators as practitioners that uses evidence-based strategies to address achievement gaps and promote equitable access to higher-level mathematics for students with diverse learning needs.

Keywords: algebra, fraction magnitude, mathematics instruction, specific learning disabilities, universal design for learning, working memory

ACTIVATING WORKING MEMORY THROUGH ACTION AND EXPRESSION: PRACTICAL APPLICATIONS OF UNIVERSAL DESIGN FOR LEARNING TO IMPROVE MATH OUTCOMES FOR SECONDARY STUDENTS WITH SPECIFIC LEARNING DISABILITIES

by

Leah Washington Zamor

Capstone submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Education
2025

Advisory Committee:

Dr. Carolyn Fink, Chair
Dr. Paula Beckman
Dr. Philip Burke
Dr. Agnesanne Danehey
Dr. Victoria Page-Voth
Deans Representative: Dr. Patricia Alexander

ACKNOWLEDGMENTS

I express my deepest gratitude to my husband Chris—my best friend, my *Leah whisperer*, my dearest confidant. Thank you for continuously pushing me to be my best and for your unwavering support throughout this journey. To my boys, Anthony and Aaron, you and your dad gave me the strength and courage to embark on this path—not only for myself but also to inspire you to set your minds on your highest goals and to know with certainty that you can reach them.

To my Mom and Dad, Lisa and Jilly, thank you for your unwavering support.

I love you all dearly.

I am also sincerely thankful to my advisor, Dr. Carolyn Fink, for her guidance, encouragement, and expertise, which were invaluable in helping me complete this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CAST	Center for Applied Special Technology
DV	Dependent Variable
EAS	Expert Alliance of Scholars
ELA	English Language Arts
ESN	Extensive Support Needs
FoA	Focus of Attention
IDEA	Individuals with Disabilities Education Act
IEP	Individualized Education Program
IV	Independent Variable
LD	Learning Disability
LTM	Long-Term Memory
MD	Math Difficulties
MDRD	Math Difficulties and Reading Difficulties
MSBI	Modified Schema-Based Instruction
MWM	Mathematics and Working Memory
NAEP	National Assessment of Education Progress
NCES	National Center for Education Statistics
NMAP	National Mathematics Advisory Panel
NTACT	National Technical Assistance Center on Transition
NU	Non-Unit
OECD	Organisation for Economic Co-operation and Development

PD	Professional Development
PISA	Program for International Student Assessment
PoP	Problem of Practice
SBI	Schema-Based Instruction
SLD	Specific Learning Disability
TA	Task Analysis
U	Unit
UDL	Universal Design for Learning
WM	Working Memory

SECTION 1: INTRODUCTION AND IDENTIFICATION OF THE PROBLEM

Math Outcomes for Secondary Students With Specific Learning Disabilities

Learning mathematics is critical for promoting viability on both a national and global setting, national economic competitiveness, and the overall economic well-being of citizens and future enterprises. Theorists, including theorists from the National Mathematics Advisory Panel (NMAP; 2008) who gave recommendations on mathematics education relative to both narrative and empirical studies, stressed the necessity of bolstering mathematics education within school systems nationwide in the United States. Their report indicated a regression in the important indicators of mathematics success and the need to prioritize instruction in this content area. Specifically, over the past quarter century, essential predictors of quantitative skills, such as reasoning and problem-solving, have not been adequately developed or identified. National performance data reflect this deficiency, which signals a widespread decline in mathematical achievement that poses significant implications for the country's future.

The consequences of mathematical regression include diminishing college and career options and decreasing future income potential for students in the United States, particularly for students with specific learning disabilities (SLDs). Among students with SLDs, difficulties encountered in algebra are significant and require evidence-based solutions. Algebra is viewed as a demonstrative gateway to potential achievement in higher-level mathematics, and research has correlated success in algebra with increased college enrollment and higher employment earnings in adulthood. An NMAP (2008) report asserted that "students who complete Algebra II are more than twice as likely to graduate from college compared to students with less mathematical preparation" (p. xiii) and stressed the importance of learning mathematics in the middle and higher-level secondary classrooms.

U.S. Student Disparities in Secondary Math Performance

Secondary students with SLDs fall behind in math performance, particularly algebra, in comparison to their non-learning-disabled peers. The population of students who receive special education services are (a) students under the Individuals with Disabilities Education Act (IDEA) who have been classified with an SLD (or more broadly, learning disability [LD]), with math goals within their Individualized Education Program (IEP), and (b) students with chronic low performance who do not necessarily qualify for IDEA services but underperform below like-peers in nationwide assessments in Grade 8. The NMAP (2008) report reviewed 26 high-quality, randomized control designs that were crucial in informing educators, special education teachers, and policymakers about practical instructional approaches for students with LDs. Panelists found that explicit, systematic instruction, along with word problems, improved performance in computation. Findings possibly impacting students with SLDs included explicit, systematic instruction, teachers explaining and demonstrating specific strategies, and allowing students time to process and think through solving problems methodologically. In addition, noteworthy developments in psychology with automaticity and problem representation served as promising effective instructional strategies in reviewed studies. Of significance within the report's findings was the limited number of high-quality empirical studies on improving students with LDs' performance in mathematics. Other empirical studies have since followed suit, with empirically designing studies based on the NMAP findings often citing and finding evidence substantive to the report. However, challenges remain with system-wide implementation of intensive instructional interventions to support students with SLDs (NMAP, 2008).

The issue of disparity in math performance between students with and without SLDs is a historical and present statistical trend identified in the National Assessment of Education

Progress (NAEP), which noted the performance gap between students with and without SLDs in eighth-grade mathematics. Statistically, the performance gap of students with SLDs has progressively widened over three decades, likely exceeding these figures. Nationally, the average score gap is 40 points between SLD students and non-SLD students, with variance over time (Nation's Report Card, 2024). Myers et al. (2021) highlighted the low performance of students with and without disabilities on NAEP math assessments. The increased complexity of math concepts during the transition from elementary to secondary school exacerbates learning delays, which are significant for both students with and without learning disabilities. The authors emphasized that only one out of four high school seniors without disabilities is considered proficient in math, indicating a pervasive academic issue for all students, but further exacerbated for students with SLDs. Statistical evidence indicates that these numbers are even lower. (Myers et al., 2021). Instruction that is not attentive to the academic needs of adolescents with SLDs impedes their access to quality curriculum and instruction. Thus, the achievement gap is further widened and the success rates are reduced in higher-level secondary mathematics and subsequent high-school and postsecondary pursuits for students with SLDs.

Algebra: The Gateway to Higher Mathematical Education

Star et al. (2015) depicted algebra as a primary gateway to secondary math education, such as geometry and calculus. Algebra requires abstract thinking and moves students beyond nonlinear numeric relationships and the representation familiarity of arithmetic. Algebraic knowledge is critical to success in postsecondary science and technical careers since algebra requires proficiency in representations such as symbols, equations, graphs, and the ability to think logically (Star et al., 2015). Unfortunately, students with SLDs underperform nationwide in algebra in comparison to their nondisabled peers, thus creating an urgent and chronic disparity gap that educators and researchers in the field of education continue to work to address as an instructional practice. Although all students encounter difficulties in mastering mathematical concepts, students with SLDs fall further behind due to instructional approaches that do not effectively address their unique learning needs, a finding that is statistically evident in the Nation's Report Card (2024).

Working Memory Links to Algebra

Stating the need for additional high-quality research to address nationwide math challenges, the NMAP (2008) panel also identified a few methodological studies examining instructional practices to improve learning outcomes for SLDs. Recommendations included instruction dedicated to students possessing skill sets in foundational math skills and conceptual knowledge critical for understanding mathematics at their respective grade levels. High-quality research in these areas is lacking, and the NMAP stressed the need for empirical investigation to address the challenges of deficit rigorous studies designed to improve instructional practices for students with LDs. Further, investigators noted that "little is known about the source of their difficulties in other core areas, including fractions and algebra" (NMAP, 2008, p. 32). While the report highlighted the need for more research on the cognitive mechanisms (which can include working memory [WM]) that contribute to LDs in mathematical domains beyond whole number arithmetic, the report did not explicitly connect WM to students with LDs or their challenges in algebra. The NMAP panel recognized gaps in understanding the sources of LD students' difficulties in algebra and called for more research but did not directly link WM to these difficulties. Despite the report non-explicitly connecting WM with students with SLDs, NMAP authors acknowledged the significance of WM on success in algebra. The report revealed that developing students' automaticity in computation facilitates WM to direct attention to more complicated aspects of complex tasks. Additionally, the report mentioned that practice allowed students to achieve automaticity, thereby freeing up WM to facilitate aspects of problem-solving capability for students (NMAP, 2008).

In Cowan et al.'s (2023) recent study, they acknowledged the lack of research connecting WM and mathematics as causal links to math performance, noting in their literature review that most historical studies focus on individual differences in WM rather than how WM can affect mathematics. Specifically, experimental designs are of limited to no use in identifying WM process engagement during problem-solving in algebraic processing. By investigating the WM processes in higher-level mathematics (Cowan et al., 2023), they identified in their quantitative study gaps in empirical evidence as a problem in the research.

Witzel and Mize (2018) also noted the urgency of adopting inclusive approaches that consider all students—including those diagnosed with SLDs such as *dyscalculia*, who often experience difficulties with WM and reasoning. However, despite growing recognition of the challenges for such students, there remains a notable gap in the empirical literature regarding applied WM strategies as intensive instructional interventions in mathematics, particularly for students with SLDs.

Teaching Challenges in Secondary Mathematics

Although many teachers believe they effectively differentiate their instruction and understand their students' capabilities, research suggests otherwise. Contrary to deeply held teacher beliefs, lesson design must intentionally be tailored to the individual needs of each student, a practice that requires a broader set of instructional skills than many teachers currently possess. Compounding this issue is the variability and inconsistency of pedagogical training provided to pre-service educators; many teacher preparation programs fail to adequately equip future teachers with evidence-based instructional methodologies (Griful-Freixenet et al., 2021).

As a result, practicing educators often lack the necessary pedagogical expertise to appropriately engage diverse learners, particularly students with SLDs. This challenge is especially pronounced in middle-grade mathematics, wherein teachers frequently struggle to identify and implement practical instructional approaches for supporting students with SLDs in mastering critical mathematical concepts (Soares et al., 2018). To aid teachers with systematic instruction to meet the needs of a diverse population, universal design for learning (UDL) principles serve as a framework of guidelines and considerations that guide instruction methodologies that focus on learner interests and target models of instruction based on student strengths, talents, and abilities. UDL, by design, targets three primary brain networks for learning—*affective*, *recognition*, and *strategic*—through an inclusive framework (Center for Applied Special Technology [CAST], 2025). Such flexible considerations support teacher individualized interpretation and added flexibility tailored to instructional needs to allow access to learner variability and can support instruction systematically.

Math Interventions' Links to UDL

The integration of evidence-based WM support by educators within the UDL framework presents a promising yet underexplored avenue for improving mathematics outcomes for these learners. CAST (2024) explained that UDL is grounded in the principles of neuroscience, the learning sciences, and cognitive psychology. UDL functions as an inclusive educational framework that fosters student-centered learning in the least restrictive environment, benefits those with disabilities, and improves education for all learners. UDL's three primary principles guide instructional practices by encouraging educators to align teaching strategies with learners' interests and to design instructional interventions that build on students' strengths, talents, and abilities. The *UDL Guidelines 3.0* (See Appendix A) provide an inclusive framework that briefly outlines the three guidelines, *multiple means of engagement*, *multiple means of representation*, and *multiple means of action and expression*, that shape instructional approaches responsive to learner variability. Within the UDL framework, engagement emphasizes learners' interests and unique abilities while addressing variability across the classroom and focusing on the influence of intrinsic and extrinsic motivation and its implications for student learning. Engagement considerations also include instructional strategies that optimize relevance, value, and authenticity for students, thereby enhancing their academic learning experiences.

The representation principle addresses learners approaching content differently based on the adverse impact of varied disabilities on processing and information comprehension. UDL guideline-based considerations include flexible pathways for accessing and interpreting information and encouraging educators to design lessons to address learning barriers. Principle, action, and expression directly connect to executive functioning and cognitive processes, particularly through the development of working memory. Action and expression considerations are linked to strengthening problem-solving and reasoning skills and to bridging conceptual understanding.

These principles support educators in designing learning experiences that honor student interests, strengths, talents, and abilities. The *UDL Guidelines 3.0* provide an inclusive framework that can be applied across diverse classroom settings, thus offering flexible checkpoints and options that allow teachers to adapt instruction. UDL's flexible model ensures access to learning, particularly for students with disabilities, by supporting teacher decision-making and tailoring instruction to meet the unique needs of diverse learners in the general education classroom (CAST, 2024a).

Challenges exist in adopting WM as a UDL mechanism despite researchers and policymakers affirming the significance and benefits of UDL principles in fostering an inclusive education environment. Historically, recent federal legislation reflects the importance of universally designed instruction and serves as a key component of the Every Student Succeeds Act (2015). However, evidence-based, research-defined instructional research on the implementation of UDL still needs to be explored by education agencies. Thus, there is an imbalance between legislation's efforts to advance a universal design for inclusive classrooms and the lack of sufficient empirical research measuring the effectiveness of UDL's system-wide intervention implementation and its impact on student achievement. The contributing factors are that UDL's potential resides in its flexible approaches through its guidelines and considerations, but this capability adds a level of complexity to effectively measuring UDL's effectiveness empirically. Thus, despite all the components of UDL principles, guidelines, and considerations that have been examined in empirical research, understanding the actual effect on diverse learners with and without disabilities remains a significant challenge as an intensive intervention approach to instruction (Rao et al., 2014).

Problem of Practice

The research will address how instructional practices grounded in the UDL action and expression principle can activate WM to strengthen algebra skills and reduce academic performance disparities among secondary students with disabilities. The problem of practice (PoP) significantly impacts subsequent academic performance for students with SLDs in secondary math classrooms, thus dictating further research. NAEP data show a decade of downward performance trends that demonstrate statistical evidence of students with SLDs in mathematics struggling to meet proficiency standards. In addition, missing foundational skills further compound their academic challenges and limits future postsecondary opportunities. Although nondisabled students encounter difficulties in mastering mathematical concepts, students with SLDs fall further behind due to instructional approaches that do not effectively address their unique learning needs. Researchers and policymakers stress the necessity of identifying and implementing individualized instructional strategies to bridge this gap and enable students with SLDs to succeed alongside their peers.

The PoP significantly impacts targeted populations of students with SLDs in secondary and post-secondary settings, and this study's focus on individuals with SLD populations who have been negatively impacted or marginalized in an area of education is supported by statistical data. Teachers need strategies to reach students with SLDs and enable them to reach their academic potential. The literature informs product design and development, draws connections between previous literature and current research in the area, and addresses limitations.

Underperformance by students with SLDs has increased the frequency of least restrict environment placement, problematic behavior, and time out of class associated with pulling students out from the general education setting. Pervasive deficits for students with SLDs widen the gap of access to math curriculum and requisite math skill sets necessary for accelerated grade-level mathematics. In addition, missing foundational skills further compound their academic challenges and limit future postsecondary opportunities. Research is necessary to identify and implement individualized instructional strategies to bridge this gap and enable students with SLDs to succeed alongside their peers.

These implications impact graduation pacing and postsecondary college and career readiness. Stakeholders affected by and able to respond to this problem include parents, secondary general math and special educators, impacted students, and specialists on the student's individualized education team. These stakeholders are integral to ensure an IEP design that meets the needs of their students with SLDs in the general education math classroom.

Moreover, paradigm shifts in professional development (PD) necessitate an increased skill set in diverse teaching methodologies. Many educators need more pedagogical training to effectively provide access to learning through the relevance of math in their lessons. This lack of training can significantly impact academic performance of students with SLDs in math.

Research Questions

This investigation sought to address the PoP regarding how educators can effectively support secondary students with SLDs in mathematics, particularly in algebra, through a standardized UDL process. The researcher revealed the following key factors that guided this study: (1) identification and leveraging of skill set predictors of algebra success, (2) challenges in secondary mathematics for students with SLDs, (3) the role of WM in mathematical performance, and (4) UDL action and expression for student learner agency. The included literature review guided how UDL action and expression, as an instructional plan, can serve as an intensive intervention to activate WM and support students with SLDs in learning the essential math skills necessary for success in secondary mathematics.

Here is a list of this study's research questions (RQs), along with explanatory information, that guided the review and informed the development of an instructional product for secondary math practitioners:

1. What skill sets are fundamental as a predictor of success in algebra and subsequent secondary mathematics? The literature identified foundational skill sets in fractional magnitude and relational knowledge as possible predictors of secondary math success and a significant factor in aiding students' ability to recognize numeric relationships in algebraic reasoning.
2. What are the challenges that students with SLDs encounter in secondary mathematics, and how do these challenges impact their learning? Key considerations include:
    a. Attention to instruction.
    b. Difficulties related to WM.
3. Is there a functional relationship between implementing the UDL action and expression principle to activate WM through executive functioning to attend to math instruction? Sub-questions include:
    a. How can the UDL action and expression principle's Guideline 6—Strategy Development (specifically Considerations 6.1: Set Meaningful Goals, 6.2: Anticipate and Plan for Challenges, and 6.3: Organize Information and Resources)—be implemented as a structured process instructional intensive intervention to support secondary students with SLDs in algebra?
    b. How can UDL's action and expression guidelines functionally support and indirectly activate a student's WM?

Future Implications

This capstone project focused on potential solutions to narrow the gap between the math performance of students without SLDs and students with SLDs. Potential solutions can lead to UDL, but limited research exists in this area of mathematics instruction. Answers to the RQs will serve as a resource to inform school administrators about instructional improvement processes targeting general and special math educators. Targeted outcomes to enhance math instruction will increase academic achievement for students with MD, specifically students with SLDs. The study's findings and the developed product will foster teacher efficacy and belief systems. The intent is to boost teacher confidence and foster their willingness to execute an intensive instructional model that will narrow the achievement gap in secondary mathematics for students with SLDs. In addition, enhancing mathematical engagement in algebraic expressions and equations should prepare students with SLDs for rigorous secondary mathematics instruction and application in preparation for postsecondary pursuits, be it via collegiate or technical pathways.

SECTION 2: COMPREHENSIVE RESEARCH REVIEW

Performance in Math for Students with SLDs

The importance of addressing underperformance in math for students with SLDs is indicated by over 2 decades of nationwide assessment data that consistently show that students with SLDs underperform in mathematics, particularly in algebra, when compared to their nondisabled peers. Achievement gaps in algebra are especially significant, given research assertions that deficits in algebraic skills hinder subsequent achievement in secondary math disciplines as well as potentially impact college and career readiness for this population of students. The Nation's Report Card (2024) continues to highlight a widening performance gap, with SLD students scoring, on average, 40 points lower than their peers. These disparities are especially evident during the transition from elementary to secondary mathematics, when conceptual complexity increases and instructional practices often fail to meet the needs of students with SLDs (Myers et al., 2021).

A review of NAEP statistical data identified lagging disparity gaps facing students with SLDs compared to their nondisabled peers in eighth-grade mathematics. Powell et al.'s (2019) research affirmed that algebraic challenges begin early in a student's school career. Some studies point to elementary school math performance issues, but this project is limited to secondary performance. Struggling with algebra in middle school can lead to difficulties with mathematics coursework in high school and influence decisions to pursue post-secondary education and persist through and graduate from college, or it can outright prohibit access to such pursuits (Powell et al., 2019).

Plausible skills necessary for algebraic success include foundations in fractional understanding (recognized in the research as a critical precursor to algebraic success), which represent both part-whole relationships and division (thus mirroring algebraic structures and expressions to support algebraic readiness). This postulation is significant for drawing explicit connections between fractional reasoning and algebraic thinking. DeWolf et al. (2015) shed light on the importance of students' ability to navigate both relational and numerical representations of fractions in comprehending algebraic forms. Fuchs et al. (2014) found that interpreting and manipulating fraction magnitudes engages WM, a factor especially relevant for students with LDs in mathematics. Ching and Li (2024) further noted that a relational understanding of fractions equips learners to generalize mathematical patterns, such as transforming proportional relationships into expressions like $3x = y$. These studies briefly highlight the potential importance of fractional knowledge in enhancing cognitive resources to facilitate the learning of algebraic reasoning, thereby emphasizing that fraction contributors have both a conceptual and cognitive connection to algebra and reinforcing their significance in algebraic development.

UDL offers a promising framework, particularly through engagement strategies and memory-based instructional approaches that activate WM by interpreting and manipulating fractions, thereby supporting these learners more effectively. Implementing UDL in mathematics classrooms can help bridge the gap by providing flexible, individualized, and empirically grounded individualized intensive instruction. However, in the absence of tools to promote fidelity of intensive instruction, students with SLDs could fall further behind their nondisabled peers, potentially jeopardizing both their secondary math achievement and their postsecondary college and career readiness.

Method

All studies reviewed included empirical and descriptive searches that targeted studies between 2014 and present (no end date). Despite falling outside the inclusion criteria for publication dates, Booth et al. (2012)—which served as a basis for later studies that further examined the role of fractional magnitude in algebraic reasoning, including Siegler et al. (2012), who identified specific fraction-related skills critical for algebraic success—was included. Similarly, Fuchs et al. (2014) was included, despite their focus on elementary-aged students, due to the significance of their findings for students at risk for mathematical learning difficulties related to developing interventions through testing attentive challenges that may have affected learning in fractional knowledge. The topic drew connections to how students learn conceptually and contributed to meaningful insight into cognitively connected interventions that may support students with SLDs in developing the fractional reasoning skills essential for algebraic understanding. The PRISMA diagram referenced (see Appendix B) provides a visual of studies contributing to the continuum of research that not only shaped the current understanding of the components of fractional magnitude leading to possible algebraic development but also added value to formulating plausible interventions in support of algebra readiness.

EBSCO databases included Education Source, ERIC, Psychology, and Behavioral Sciences Collections. Inclusion criteria applied the following: (a) peer-reviewed research in English; and (b) single-subject, quantitative, mixed-methods, qualitative, and literature review/synthesis within 10 years of publication from 2024. Studies included secondary students and education settings (Grades 6–12), specifically in the general education mathematics classroom.

The literature review focused on empirical studies, mixed-methods, qualitative, quantitative, single-subject, and quasi-experimental studies in secondary math, specifically at the middle school level, and psychology-based studies on brain functions relating to memory retrieval and attentiveness. The majority of the research articles used were peer-reviewed articles. However, alternative resources, such as government reports independent of EBSCO, ERIC, and Education Source databases, played a significant role in supporting the PoP by providing statistical student performance data over long duration time periods. These reports or agencies, such as the What Works Clearinghouse, Office of Special Education Programs data reports, National Center for Education Statistics (NCES), Organisation for Economic Co-operation and Development's (OECD's) Program for International Student Assessment (PISA) 2022 report, and the Nation's Report Card/NAEP data (2024) served as statistical, empirical studies operationally defined and data-based reporting agencies identified students with disabilities and academic challenges to inform how best to address root causes of learning deficiencies in components of the design of the product for practitioners..

The PISA report (OECD, 2023) substantiated the use of international studies in the literature review and served two purposes. First, the report offered a broader comparative framework for understanding the historical trajectory of mathematics education in the United States; second, the report contextualized the persistent gaps in key mathematical competencies, such as fraction fluency and algebraic reasoning. International research reinforces the urgency of addressing foundational mathematics skills and provides evidence for re-examining instructional design in mathematics. By situating U.S. student performance within an international context, the review highlighted global trends and specific areas of instructional need that this study sought to address. International cohort data lends credibility to studies investigated across different countries. The NAEP report card and analysis used for statistical data referenced historical performance indicators dating back to 1996. Peer-reviewed empirical study inclusionary factors were from 2014 to 2025. In addition, reference management software, such as Papers, streamlined the research process and identified complementary studies that lent to empirical research review and analysis. Prioritized studies were specific to eighth-grade math and specific to UDL and engagement representation as an intervention. Older studies outside the inclusion criteria provided foundational documentation of challenges for students with SLDs.

This literature review examined the intersection of mathematics instruction, WM, and UDL, with a focus on effective instructional strategies for secondary students with LDs and MD. A structured and thematic search strategy was applied across the ERIC, EBSCOhost, and PsycINFO databases, targeting peer-reviewed literature published in English. The search process focused on three key thematic categories: *mathematics*, *WM*, and *UDL*. Within the mathematics category, search terms included *fractions*, *algebra*, *interventions*, *WM*, *learning disabilities*, and *math difficulties*. A secondary, more narrowed focus within the math theme concentrated specifically on *fractional knowledge* and its relationship to WM. This narrow focus led to subsequent searches that focused exclusively on WM and cognitive functioning as they relate to mathematical understanding and performance. Boolean combinations used in this phase included the following: "*fractions* AND *interventions* AND *working memory*," "*algebra* AND *interventions* AND *working memory*," and "*orthography* AND *students with learning disabilities* AND (*math difficulties* OR *mathematical difficulties* OR *math struggles*)."

The WM theme focused on cognitive mechanisms that influence learning, using terms such as WM, short-term memory, and executive function. Refined search terms, used both independently and in conjunction with mathematics- or UDL-related terms, explored the cognitive underpinnings of mathematical learning challenges and informed intervention design and resulting measured effectiveness.

In the UDL category, search terms included *universal design for learning*, *UDL*, *universal design*, and *WM*, often paired with *short-term memory*, *executive function*, or *mathematics*. Boolean combinations such as "*universal design for learning* OR *UDL* OR *universal design* AND (*working memory* OR *short-term memory* OR *executive function*)" and "… AND *mathematics*" yielded 91 initial results after exclusions. The combination "… AND *secondary mathematics*" yielded 26 relevant sources. An additional 57 articles across ERIC, EBSCO, and PsycINFO, under general UDL and WM searches with exclusions identified, resulted in five articles that met the inclusion criteria after full-text screening.

To further refine the UDL focus, a backward search using the CAST was conducted, stemming from initial literature connecting mathematics instruction and WM. This approach narrowed the UDL analysis specifically to the action and expression principle outlined in *UDL Guidelines,* Version 3.0. The CAST repository and its foundational literature identified guidelines and connected considerations associated with *cognitive functioning* (e.g., *executive function*, *strategic memory*, and *planning*), thereby aligning the review with instructional strategies that support diverse cognitive load needs in math education for students with SLDs.

Regarding UDL, exclusion criteria application ensured the inclusion of only studies with clearly defined, operationalized, and empirically measured applications of UDL. This approach aimed to maintain the integrity and relevance of the literature review in identifying predictors of success in algebraic performance related to fractions. Studies that merely referenced UDL principles without operationalizing them within the instructional intervention or study design were excluded. For instance, research that mentioned UDL in another intervention but did not evaluate or measure the impact of UDL itself did not meet the inclusion criteria. A content matrix (see Appendix B) served to catalog the literature, including study quality criteria by methodology type. Quality assurance factors included the Council for Exceptional Children (Cook et al., 2014) quality indicators for quantitative studies, comprehensive interventions, attrition rates, and overall validity of the empirical design and results, as appropriate to the study reviewed. Qualitative quality indicators from the National Technical Assistance Center on Transition (NTACT) quality guidelines (Lattin, 2024), which were adapted from Brantlinger et al. (2005) and Trainor and Graue (2014), ensured research-based quality for the studies analyzed. NTACT includes quality indicators for mixed-method and single-subject studies for quality assurance, adapted from Horner et al. (2005), Kratochwill et al. (2012), Onwuegbuzie and Corrigan (2014), and Onwuegbuzie and Poth (2016).

The content matrix affords investigators an overview of the research purpose, questions, participants, design type, variables as applicable, and the study's results, thereby serving as a consistent reference and conceptual guide for seeking answers to the RQs. Additionally, matrix coding provides comprehensive and concise information on the quality and validity of the empirical research reviewed. Studies with the RQs' stated purpose aligned to inclusion factors served as the priority research to review and synthesize, thus ensuring their relevance and impact. A total of 1,644 records were initially identified: Of those, 1,589 were excluded after screening titles and abstracts due to irrelevance or duplication. Of the remaining 55 full-text articles reviewed, an additional 20 were excluded for not meeting inclusion criteria (e.g., not peer-reviewed, not focused on secondary education, or lacked relevance to LDs or cognitive support). In the final synthesis, 35 articles were included, 20 of which directly addressed the RQs and 15 of which served as supporting literature. All empirical studies reviewed met the inclusion criteria. RQ 1 pertained to predictors of algebraic success, particularly in terms of students' understanding of fraction magnitude, relational reasoning, and unit (U) coordination. These foundational skill sets consistently emerged as critical precursors to algebra readiness, highlighting fractional knowledge concepts as gateways to algebra, which itself served as a gateway to higher-level mathematics.

RQ 2 placed challenges faced by students with SLDs into two major domains—attention and WM—relative to mathematics-specific difficulties. The studies referenced acknowledge and work to address deficits in WM and attentional control, which hinder students' capacity to engage with complex algebraic tasks, including addressing cognitive load implications in mitigating these math difficulties.

RQ 3 situated UDL as a framework for addressing these barriers. The literature revealed that UDL, particularly the action and expression principle, has the potential to enhance student executive function, thereby clearing the way for students with SLDs to work on their WM in mathematics learning. Meta-analyses and applied studies reveal that embedding UDL principles into math instruction fosters accessibility and flexibility, especially for learners with diverse needs. Overall, the literature established a coherent evidence base by identifying predictors of algebra success, understanding the challenges faced by students with SLDs, and exploring UDL as an intensive instruction intervention to bridge performance gaps in mathematics for students with SLDs compared to their nondisabled peers.

Literature Review

Predictors for Algebraic Success in Secondary Mathematics

Determining factors that lead to increasing student proficiency in mathematics, specifically in Algebra I, dictated delving into the root causes of math difficulties among students with SLDs in secondary math. Findings have practical implications in identifying determinant skill sets necessary for students with SLDs in mathematics to be successful in algebra and subsequent higher-level mathematics. The NMAP (2008) report proposed three clusters of skills and concepts (see below) deemed essential for students to master before engaging in algebra coursework. Major topics identified included whole numbers, fractions, positive and negative numbers, and the arithmetic of rational numbers, with a complex progression from numerical computations to symbolic manipulations. Each cluster served as a determinant of algebraic success.

The first cluster, *fluency with whole numbers*, emphasizes students' understanding of place value and the ability to manipulate whole numbers using the commutative, associative, and distributive properties, particularly in problem-solving. In the middle grades, instruction expands to include aspects of geometry and measurement relevant to algebra, such as properties of two- and three-dimensional shapes and formulas for shape calculations. The second cluster, fraction fluency, emphasizes a comprehensive understanding of positive and negative fractions, including the relationship between fractions, decimals, and percents. This fluency supports the development of estimation skills and computations involving proportionality and probability.

The third and final cluster focuses on particular aspects of geometry and measurement as an essential aspect of mathematics significant for algebra success. Further, the acquisition of triangulation skills by middle-aged students, such as recognizing the slopes of a line and a linear function, was noted as relevant and supportive of algebraic knowledge. Overall, NMAP panelists prioritized a math focus on fractions—with proficiency with fractions, including decimals, percents, and negative fractions, the most important math skill not presently developed—as critical for improving student performance in algebra (NMAP, 2008, p. 18). Recent studies from Booth et al. (2014) quantitatively confirmed the NMAP's findings, noting that having a solid foundation of fraction knowledge is important for learning algebra. Their research supported other literature that revealed that students who have a better understanding of fraction magnitudes when they begin studying algebra content learn more of that content than peers with poorer fraction magnitude knowledge (Booth et al., 2014). Myers et al. (2021) further supported comprehensive identification from historical research cited, highlighting fractions, ratios, proportions, algebra, computation, whole numbers, and application of complex math skills and knowledge of solving mathematical problems as a precursor to the successful completion of algebra by students with SLDs, thus solidifying the reliability of the research (Myers et al., 2021). Accordingly, this study examined students' fraction knowledge and the development of related skill sets essential for algebraic success.

Fractional Knowledge and Relational Thinking

Booth et al. (2012) examined the relationships between fraction and whole number magnitude knowledge and performance in algebra, investigating the numeric relationship comprehension of students with math difficulties. The authors examined differences between students' understanding of numerical magnitudes and their readiness for algebra. By collecting data using numerical analysis, they identified significant implications for teaching and learning algebra, necessitating further study. Researchers measured algebraic readiness by testing students via paper and pencil on dependent variables (DVs) as measures of algebra readiness. Measures included feature knowledge, equation solving, and word problem solving. The independent variable (IV) included testing knowledge of fraction and whole-number magnitudes through number line tasks. Data analysis procedures included repeated measures of the analysis of variance (ANOVA) with a significance threshold of $p < .01$ to evaluate the linearity of numerical magnitude estimates across different numerical scales. In addition, paired-sample *t*-tests with Bonferroni corrections to compare linearity between these scales revealed a main effect of task, indicating that students' magnitude representations were stronger with the whole-number scale than with the fraction scale. Analyses of unfamiliar, more complex non-unit (NU) fractions suggested that performance on these items may have tapped students' proportional reasoning and was marginally related to equation solving. Researchers deliberated on why fraction magnitude knowledge is important for algebra and hypothesized that knowledge of fraction magnitudes better represents deep number knowledge than whole number magnitude knowledge. The authors argued that a student's ability to accurately place or compare NU fractions correlated with success in equation solving and word problem performance, suggesting that understanding these more complex magnitudes was crucial for algebra readiness. Algebra requires comfort with abstract relationships between quantities, something that fraction magnitude knowledge helps to develop.

The results of this study shed light on the crucial role of foundational numerical magnitude knowledge for students with math difficulties as well as on the role of a fundamental understanding of numbers represented by quantities such as NU fractions. Booth et al. (2012) asserted that these relationships shaped various aspects of algebra readiness and provided valuable insights for the review. Intent on extending the foundational work of Siegler et al. (2012), Booth et al. (2012) provided further evidence that knowledge of fraction magnitudes, more so than whole number magnitudes, was a critical predictor of students' early algebra performance. Referenced work from Siegler et al. (2012), who had previously demonstrated that fraction magnitude understanding uniquely linked to algebra readiness, added a conceptual basis for mathematical development beyond procedural competence: the ability to apply procedures accurately. The literature defines *fraction magnitude knowledge* as a core component of overall fraction knowledge. Magnitude and fractional knowledge are directly connected, with Siegler et al. (2012) asserting that understanding the size of fractions (magnitude knowledge) was more fundamental to long-term mathematical success than simply knowing how to compute fractions.

Expanding on this concept, Booth et al. (2012) clarified that algebra readiness involves more than procedural skill with fractions; it also requires a fundamental understanding of their magnitudes. As a further illustration, they examined how students placed disparate fractions, representing various fraction types on a number line, to identify the most significant knowledge components associated with algebra success. Results showed that placement accuracy, especially with unfamiliar and complex NU fractions, likely engaged students' proportional reasoning. To distinguish between fraction types, U fractions had a numerator of 1 (e.g., 1/2, 1/5, 1/10), whereas NU fractions had numerators other than 1 (e.g., 3/4, 5/6, 7/10). The researchers noted that placing U fractions requires identifying the size of one part, while NU fractions demand proportional reasoning to integrate both numerator and denominator values.

The study found that student performance on these tasks significantly correlated with equation-solving, word problem-solving, and feature knowledge and was marginally related to equation-solving performance. By substantiating and extending Siegler et al.'s (2012) earlier findings, Booth et al. (2012) added further credibility to the theoretical connection between fraction magnitude understanding and algebraic proficiency.

Booth et al. (2014) extended their research by further examining the correlation between fractional magnitude knowledge and students' understanding of basic numeric relationships, particularly the interplay between numerators and denominators. For example, how students understand one part of the fraction, the numerator, is dependent and affects understanding the other part, the denominator. Overall, the interplay refers to the relationship between two numbers to grasp the concept of fraction size. They identified this relationship as one that is often difficult for some students with SLDs to recognize and maintain, both in secondary and postsecondary educational contexts. The literature analysis highlighted the role of students' relational thinking in numeric relationship comprehension and pattern recognition, which activates WM through the brain's central executive system. These patterns led to further exploration of attentiveness to instruction in connection with fractional knowledge and the implications of a deeper understanding of numeric relationships.

Booth et al. (2014) asserted that strengthening relational thinking-intensive strategies developed from the research could lead to algebraic success for students with SLDs. The study had three primary purposes and hypotheses tested, including replicating and extending Booth and Newton's (2012) previous study on the relationships between fractions and whole number magnitude knowledge. Additionally, it aimed to test the predictability of fraction versus whole number magnitude knowledge influence in algebraic learning. They sought to replicate and extend previous findings on the relationship between fraction and whole number magnitude knowledge skills for students taking algebra. The authors hypothesized that the role of fraction knowledge in algebra performance was limited to automaticity, and they expected to find a relation between fraction magnitude knowledge and learning in equation solving as well as measures of conceptual understanding, thus working to add specificity to determinants of fraction magnitude knowledge. Finally, they examined the role of magnitude knowledge by U versus NU fraction implications on algebra performance and student learning, thereby extending previous research asserting the importance of U fractions for algebra readiness. The authors hypothesized that NU fractions, as evidenced by placement, were synonymous with proportional reasoning and were of greater importance for algebra readiness. Their reasoning included that students with a better understanding of fraction magnitudes learn more of the content when they begin studying algebra than their peers with poorer fraction magnitude knowledge. This assertion is due to students' understanding of the relative sizes of fractions and assessing them through tasks like placing fractions on a number line. This understanding involves recognizing the relationship between a fraction's numerator and denominator, which is crucial for developing concepts such as fraction equivalence and proportionality. Finding relationships between fraction magnitude knowledge and learning in equation solving was significant to the study and a critical skill set in algebra. Finally, researchers examined the roles of magnitude knowledge for the U versus NU fractions and its implications on algebra performance.

Booth et al.’s (2014) empirical methodology was thorough, with quantitative procedures including an Intervention Cognitive Tutor with a pre- and post-test to assess learning. No control group was assigned to the study. Each measure included results of several items tested with reliability statistics, ANOVA values, and comparisons between pre- and post-test deviations and means. Participants consisted of 72 eighth-grade students from all skill levels (37 female, 34 male, and 1 unspecified gender) across five classrooms in a single school in which 29% of students were classified as low socioeconomic status. Skill levels were not explicitly defined or representative of the school’s population of eighth-grade students. The ethnicity breakdown for participants was as follows: 28% Caucasian, 61% African American, 3% Asian, 4% Mixed Race, and 4% Other or Unspecified Race. Limitations included specific testing of students with SLDs specifically identified. Researchers noted that participants had varied math skill sets. Attrition rates met quality criteria, with a low attrition rate of less than 1%. After completing the U, the classroom teacher administered the post-test to each student as soon as possible. In this study, the average time students spent with the tutor was 3.4 class periods (SD = 1.6). All students completed the study within 3 weeks. Three measures of algebraic knowledge were administered:

feature knowledge, equation solving, and equation encoding. As a reconstruction task, participants were given a timed visual algebraic equation via an overhead projector.

Booth et al. (2014) found partial correlations between U and NU fractions and post-test scores on the three knowledge measures controlling pretest performance. They revealed that NU fractions significantly correlated with improvement in the equation solving and equation encoding tasks, whereas U fractions related only to improvement on the encoding task. This correlation suggests that a better understanding of NU fractions is more beneficial for improving algebraic skills. NU fractions contributed significant variance toward predicting improvement on the encoding task, whereas U fractions did not. Thus, NU fractions are more significant in predicting algebraic success than U fractions.

The equation encoding was significant to the study but not fully explored, with only one fraction correlation with improvement in equation solving and encoding tasks. As a reconstruction task, participants were given a timed visual algebraic equation via an overhead projector. Immediately after the equation disappeared, participants reconstructed the problem from memory. The equation encoding aimed to test for attention to critical features of algebraic equations. Participant responses were coded based on the number and type of errors. Coding categories were non-conceptual, such as number switching, and conceptual features, such as positive/negative, equal, or variable signs. Pretests and post-tests were on the number line, equation encoding, feature and fraction knowledge, and equation solving. Participants worked independently on Cognitive Tutor (IV), with the study completed within 3 weeks and with less than 1% attrition of participants.

The study’s findings have significant implications for educators, researchers, and policymakers interested in mathematics education and student learning outcomes. The study demonstrated that fraction magnitude knowledge is predictive of students' improvement in algebra, affirming the NMAP (2008) theory of a solid foundation of fraction knowledge serving as an important factor for learning algebra. Booth et al. (2014) asserted that students who better understand fraction magnitudes when they begin studying algebra learn more of that content than peers with poorer fraction magnitude knowledge. The study also suggested that equation encoding, while significant, was not fully explored, but it hypothesized that attention to instruction could be a supporting factor in algebraic success (Booth et al., 2014).

DeWolf et al. (2015) aimed to build connections with Booth et al.'s (2012) previous research testing secondary students' prior knowledge of rational numbers, fractions, and decimals to indicate readiness and success in algebra. Specifically, researchers sought to assess whether fraction magnitude or relational understanding of fractions is a more critical predictor of algebra performance and to compare the predictive power of magnitude tasks involving fractions and decimals. Analytic methods using multiple regression analysis revealed relational fraction knowledge as the best probable indicator of algebra performance. The study identified two specific measures providing more accurate predictors of math performance: (1) performance of division operation based on the relationship between numerator and denominator, and (2) approximation of the resulting magnitude on the physical number line (DeWolf et al., p. 78, 2015). Researchers recognized magnitudes as a critical aspect of mathematical knowledge and added understanding mathematical relations as an additional skill in grasping algebra. The duality of fractions, in partnership with mathematical relationships, represents the magnitude of both the numerator and denominator, or division of *a* by *b,* similar to the duality of algebraic expressions.

DeWolf et al. (2015) noted:

> Students must understand that they can use algebraic expressions to represent both the relations between quantities and the process used to find an unknown quantity. For example, the quantity of four boxes of equal weight can be represented as 4w without knowing the actual magnitude of a box's weight. The expression *4w* represents the combined weight of the boxes and the process (multiplication) that could be used to determine the total weight given the actual weight of one box. (p. 73)

Thus, students' conceptual understanding of fractions representing mathematical relations and fraction magnitudes can enhance their understanding of algebraic expressions.

DeWolf et al. (2015) urged educators to emphasize the importance of teaching students the magnitude of fractions by emphasizing number line representation to highlight relative magnitudes. Of equal importance, findings found that instruction on decimals using number line representation was less effective in preparing students for algebra, given that magnitude decimals lose relational structure and are expressed one-dimensionally. Researchers stressed the significance of developing connections between fraction and algebraic expressions, thereby acknowledging relationships and parallels between both domains for mathematical skill sets and asserting relational and numerical fraction representation may be essential for student comprehension of algebraic expressions (DeWolf et al., 2015).

Correlation with the identified PoP and age ranges associated with recent quantitative research from Ching and Li (2024) extended the aforementioned studies in fraction relational knowledge as a predictor of algebraic performance. Given limited historical longitudinal associations between fractional relation reasoning as a predictor of algebraic performance among elementary and/or secondary students, Ching and Li sought to clarify the relationships between the two by investigating comparative relative strength of fraction relational reasoning and cognitive factors predicting algebraic performance as a predictor over 18 months. The study assessed a range of cognitive predictors among fourth-grade Chinese students and followed the same participants, longitudinally tracking their performance on algebraic tasks in the sixth grade. The results echoed those of previous studies—that fraction relational reasoning significantly predicted algebraic performance, even after accounting for other factors like fraction magnitude knowledge and fraction arithmetic. Researchers supported their three hypotheses with several findings based on multiple regression analysis.

Fractional relational reasoning involves understanding multiplicative relationships between numerators and denominators and foundational algebra skills, including relational reasoning such as proportionality. Student recognition of relationship skills developed from mastery of fractions and their numeric relationships allows students to develop the ability to generalize patterns to algebraic expressions such as $3x = y$, wherein proportional reasoning plays an important role. Fraction relational reasoning further supports algebraic thinking by fostering a deeper understanding of numerical relationships and operations, thus preparing students for higher-level mathematics. Finally, fractional reasoning skill sets can support student success in algebraic reasoning more than decimal magnitude knowledge because fractions involve reasoning concerning relationships. In contrast, decimals tend to be linear and one-dimensional, further validating previous work from Booth et al. (2012), DeWolf et al. (2015), and Siegler et al. (2012).

In summary, researchers acknowledged fraction magnitudes as a crucial skill set for students with and without SLDs. Fractional magnitude aids students in recognizing abstract relationships between numeric quantities and the size of a number with other numbers. Fraction magnitude also supports pattern recognition and builds skill sets in understanding numeric quantities. Algebra requires students to be comfortable with abstract relationships between quantities, something that fraction magnitude knowledge helps to develop. This development of algebra skills is an academic benefit derived from fraction knowledge. Finally, fractional relational reasoning involves understanding multiplicative relationships between numerators and denominators and foundational algebra skills, including relational reasoning such as proportionality.

Challenges of Students with SLDs

A Delaware longitudinal study of fraction learning by Jordan et al. (2016) focused on fraction relation and magnitude numerical skill set implications for students with either SLDs in math or identified math difficulties. The quantitative longitudinal study's focus served to determine how best to address students with SLDs in mathematics performance in algebra using identified fraction determinants and instructional strategies. Jordan et al. (2016) noted key cognitive foundations referring to empirically supported research from Geary (2004) and LeFevre et al. (2010) as rationales for examining processes and skills associated with acquiring mathematical knowledge, and for studying processes and skills necessary for students with math difficulty and/or SLDs' success in algebraic performance. Students in Grades 3 and 6 identified as receiving special education services and diagnosed with a LD were disproportionately represented in low-growth fraction groups throughout the study and were 1.6 times more likely to show low growth in fraction magnitudes and 2.5 times more likely to comprehensively demonstrate low growth in fractions than their nondisabled peers. These authors found that students with learning difficulties struggled with fraction placement on the number line, determining fraction equivalents, comparisons, the order of fractions, and estimating fraction sums. These difficulties indicated a tendency for these students to identify fractions as four separate whole numbers.

Longitudinal research supports a number line approach to teaching fractions, specifically for students with SLDs in math or who are identified with math difficulties. Students whose skill set in associating fractions as one magnitude representing the numerator and denominator in regard to real numbers identifiable by the number line are disadvantaged in grasping fractions and learning future algebraic concepts (Jordan et al., 2016The authors' investigation of non-mathematical factors significantly contributing to the effectiveness of student responses to fractional knowledge was a key aspect of their comprehensive research. Their use of historical research on attentive behavior as a unique predictor of fraction knowledge and overall math achievement was exceptionally significant and insightful. A narrow analysis included the implications of the central executive system on students with SLDs and math difficulties, deeply examining the processes and skills involved in acquiring mathematical knowledge through cognitive processes. necessary for successful algebraic performance for students with math difficulty and SLDs. First, the *central executive*, *language*, and *visual-spatial systems*, identified as *cognitive processes*, influence students' ability to grasp mathematical knowledge. The central executive system is a function of attentive behavior and WM that lends to the student's ability to attend to instruction linked to math achievement. Moreover, attentive behavior is a key factor in distinguishing students with MD from students without disabilities or difficulties with typical achievement in fraction knowledge. As previously noted from studies on fraction knowledge, attentive behavior requires attention to numerators and denominators and multiple procedures.

Fractions and WM

Foundational to cognitive and behavioral research, psychological studies examining attentive behavior and its connection to WM trace back to Baddeley's (1986) model of brain function. Baddeley defined WM as the capacity to store and manipulate information in short-term memory. Elaborating on this concept, Fuchs et al. (2014), drawing from Baddeley and Logie (1999), described WM as a resource-limited system responsible for allocating attention, planning, sequencing, and maintaining information while simultaneously processing related inputs. Baddeley and Logie further identified key features of WM, such as emphasizing the role of the central executive system in regulating attention, shifting focus, and activating representations in long-term memory (LTM).

Current research remains limited in drawing conclusive links between WM and its instructional functional relationship to strengthen the acquisition of fractional knowledge necessary for algebraic success. Studies reviewed asserted that WM serves as a critical mechanism for developing fractional knowledge by enabling learners to hold and manipulate part-whole relationships and visual-spatial representations simultaneously. This coordination is essential not only for understanding fractions but also for applying that knowledge, which is foundational to algebraic reasoning. Methodological approaches, acknowledgment of varied definitions of fractional understanding, and differences in how WM is measured contribute to the challenge of establishing a clear, causal relationship. As a result, more targeted studies are needed to isolate specific cognitive processes, particularly attentional and memory-related ones, in order to support the connection between fraction competence and algebraic reasoning.

Converging literature associates attentive behavior with WM and the ability to store and manipulate short-term information, predicts problem-solving accuracy, and is strongly associated with math disabilities (Peng et al., 2015). Although the primary focus of this review is on attentive behavior related to fractional knowledge, I acknowledge the role of the language system—a noteworthy component of Jordan et al.'s (2016) study emphasizing the consideration of the role of the brain's language system in mediating that relationship and its implications for word problems and proportional relationships involving fractions. According to Jordan et al., the language system is crucial for understanding mathematical terms related to fraction knowledge and solving word problems (Jordan et al., 2016). Visual-spatial systems support student numeric reasoning within spatial contexts, such as recognizing proportional relationships in fractions. Furthermore, the review of the literature revealed that proportional relationships in fractions enhance predictors of algebraic relational reasoning. Together, these cognitive systems contribute to success in mathematics, particularly in learning fractions, and serve as an indicator of success in algebra (Baddeley, 1986; Jordan et al., 2016).

Jordan et al., (2015) assessed attentive behavior of participants using general cognitive predictors assessment types; students' math teachers completed the Inattention Subscale of the SWAN Rating Scale (Swanson et al., 2006, as cited in Jordan et al., 2016), which consisted of inattention criteria of attention-deficit/hyperactivity disorder. Geary (2004), Fuchs et al. (2005), and LeFevre et al. (2010), noted that the central executive system and the language system are a function of attentive behavior. Specifically, Fuchs et al. (2005) found that the student's ability to attend to instruction is linked to math achievement. Fuchs et al. (2005), Geary (2004), and LeFevre et al. (2010) all affirmed attentive behavior is a key factor in distinguishing students with mathematics difficulties from students without disabilities or students without difficulties with typical achievement in fraction knowledge.

Several studies likewise described attentive behavior that includes WM, defined by Baddeley (1986), as the ability to store and manipulate short-term information, a predictor of problem-solving accuracy, and strongly associated with math disabilities. In addition, Seethaler et al. (2011) noted the language system was essential for understanding mathematical terms and solving word problems. Finally, regarding visual-spatial systems, Gunderson et al. (2012) asserted that student numeric reasoning within spatial contexts was necessary for recognizing proportional relationships in fractions. Jordan et al. (2015) asserted that recognizing proportional relationships in fractions is necessary to enhance predictors of algebraic relational reasoning. Together, these cognitive systems contribute to success in mathematics, particularly in fraction learning, and are an indicator of success in algebra (Baddeley, 1986; Gunderson et al., 2012; Seethaler et al., 2011; H. L. Swanson, 2011). Psychological factors significantly contribute to developing math skills. The links from the Jordan et al. (2015) longitudinal study, which highlight the correlation between attentive behavior and achievement in fraction knowledge —a necessary building block for algebraic success —supported the research questions of the literature synthesis and the design of a product for practitioners. Fractional knowledge, as defined by Fuchs et al. (2014), involves discussing fractions in the context of part-whole relationships and the measurement interpretation of fractions, which is foundational to learning fractions. Further study also included components of fraction magnitudes and relational knowledge, which may indicate algebraic success in secondary students. The study highlighted the importance of fraction knowledge for success both in and out of school, using it as a context for their research. The investigation focused on interpreting fractions as an intervention to enhance overall fractional learning tests and the benefits of automaticity in alleviating excessive cognitive loads on at-risk students' resources in developing their fractional knowledge. The authors asserted measurement interpretations of fractions related to cognitive processes and emphasized WM and executive systems as a focus for their research. The primary RQs explored whether the effects of fluency versus conceptual conditions (aptitude-treatment interactions) differed as a function of students' WM. In summary, the researchers review stressed the critical role of fractions in supporting students' broader mathematical development, particularly in preparing them for success in algebra. For students with SLDs, this connection becomes even more significant. Studies, especially those by Fuchs et al. (2014), highlight the connection between fractional understanding and cognitive processes, such as WM, which many students with SLDs struggle with. The literature review identified fractions as important to learning; indeed, recognizing fractions not only as a content area but also as a bridge to algebraic thinking offers valuable insights for future intervention planning.

Narrowing their focus, Fuchs et al. (2014) drew upon previous empirical research hypotheses on whether more fundamental differences in processing speed propel individual differences in WM or whether the attentional focus associated with the central executive system speeds information processing through automaticity. The primary RQ derived from Geary et al.'s (2008) fluency practice compensation hypothesis was that fluency practice significantly enhances at-risk students' learning by promoting automaticity with foundational skills, thus compensating using their cognition that affects math learning. Geary et al. (2008) specifically defined WM and attentiveness as follows:

> Information processing begins when a student encounters information and lasts until that information is acted upon and a response is made. The process starts with attention, without which information is lost. Information that is the focus of attention (FoA) becomes available to learners' working memory, and with practice, the information can

be transferred to LTM. Deficiencies or superiorities in working memory capacities are major contributors to learning disabilities or accelerated learning, respectively. Improving the effectiveness of working memory can be assisted by achieving automaticity (National Mathematics Advisory Panel, 2008, Executive Summary).

WM and Attention

Based on Geary et al.'s (2008) fluency practice compensation hypothesis and the plausible role of WM as a significant factor for students with LDs, Fuchs et al. (2014) investigated WM effects on at-risk fourth-grade students' fractional knowledge. They noted historical challenges associated with the measurement of interpretation of fractions, which can potentially tax at-risk students' central executive systems because the process simultaneously requires consideration of both numerator and denominator when completing tasks and comparing fractions/or number lines (Fuchs et al., 2014). Some at-risk students often experience limited WM, inattentive behavior, and slow processing speed, thus dictating further exploration of individual differences in WM as a study justification. The researchers aimed to answer how personalized interventions could capitalize on students' cognitive strengths while reducing cognitive limitations. Significant to the study was the exploration of WM as a function of the central executive system and attentiveness to build fluency and understanding in fractional concepts.

IVs, Conditions 1 and 2, focused on the measurement of fraction interpretations based on at-risk students' ability to represent, compare, order, and place fractions on number lines on the premise that cognitive load could be reduced and improved through building fluency with strategic chunking (recoding multidimensional concepts with few dimensions) or segmenting (breaking tasks into steps) and retrieval automation of fractional values concerning benchmark fractions (Fuchs et al., 2013). The significance of the present project pertained to Condition 2, the conceptual condition, part of a tested intervention program from previous research conducted by Fuchs and Schumacher (2011). These intervention programs were designed to compensate for at-risk students' cognitive limitations associated with fraction learning (Fuchs et al., 2013; Fuchs & Schumacher, 2011). Fuchs et al.'s (2014) study investigated whether individual differences in WM moderated the effects of two intervention variations to improve at-risk 4th graders' fraction knowledge.

Methodologically, the interventions were compared against a business-as-usual control group. At-risk students (n = 243) were randomly assigned to the control and two intervention conditions, each lasting 12 weeks, with three 30-minute sessions per week. The study assessed children's WM, processing speed, attentive behavior, language, and fraction knowledge before and after the intervention (Fuchs et al., 2014). WM was measured using the Working Memory Test Battery for Children—Listening Recall Test designed by Pickering and Gathercole (2001). Attentive behavior was measured by Strength and Weaknesses of ADHD Symptoms and Normal Behavior scales taken from J. M. Swanson et al. (2012).

Both intervention conditions focused on the measurement interpretation of fractions, differing only in 5 minutes of each session. One condition included activities to build fluency, while the other focused on consolidating understanding through reasoning and manipulatives. The two 36-session intervention conditions, fluency and conceptual, comprising 30-minute sessions tested, were distinguished as fluency and conceptual condition effects against business-as-usual conditions in a typical school program. The conceptual condition was a four-measure interpretation of fractions, an extension of previous research on the importance of fractions as the basis of understanding foundational learning of algebra and advanced mathematics, the basis of the researcher's hypothesis. Apart from fluency, the conceptual condition assessed participants' ability to explain their reasoning and demonstrate a conceptual understanding of the meaning behind the four measurement interpretation topics using manipulatives. An in-depth analysis of fractional knowledge explored types of fractions, including those between any two fractions, and noted that there are infinitely many other types (Fuchs et al., 2014).

Measurement interpretation of fractions is less intuitive, requiring analysis and development through the instruction of symbolic notation, the inversion of the property of fractions (which refers to the process of converting a fraction to its reciprocal), and the infinite density of fractions on any point of the number line. Fuchs et al. (2014) noted the significance of the conceptual condition and tested for effectiveness in students' ability, derived from instruction—to consolidate understanding and explain their reasoning. In addition, correlations were determinants between students' ability to consolidate meaning and the possible attentive components connected to the central executive system and WM. The study's results associated success with aptitude-treatment interventions. Students with weak WM benefited more from conceptual activities. In contrast, those with more adequate WM benefited more from fluency activities. Both intervention conditions outperformed the control group, and improvements in the measurement interpretation of fractions mediated these effects. The study's limitations and researcher recommendations for future research discussed aptitude-treatment effects to personalize interventions to address the diverse learner (Fuchs et al., 2014). Findings from Fuchs et al. found that the interpretive component of measuring fractions was linked to a range of cognitive processes, with a particular emphasis on the role of WM. This insight sheds light on the theory that executive functioning and cognitive processes are associated with fraction interpretation and facilitated by WM, a significant component of the current research in support of students with identified LDs in mathematics (Fuchs et al., 2014). Later, Ünal et al. (2022) served to extend and address limitations in WM as an instructional functional relationship and mechanism as a contributor to algebraic problem-solving by exploring cognitive load in relation to effects on WM's role in algebra. The study by Ünal et al. (2022) serves as a transition between working on fractions and the instructional interventions required for students with SLDs.

Cognitive Load

Fuchs et al. (2014) articulated WM and its measures concerning functions that pertain to fractional knowledge skills necessary for algebraic success. However, they noted the research remained limited to the impact of cognitive load measurements on algebraic success. Ünal et al. (2022) investigated the role of domain-general attention and domain-specific processing in WM as it relates to algebraic performance. The authors specifically focused on students with mathematical LDs and MD, measuring cognitive mechanisms as a significant factor of achievement deficits in students with mathematical LDs. As such, the study aimed to understand the WM and attentional demands associated with early but critical components of algebraic knowledge and skills, such as evaluating expressions and placing ordered pairs in the coordinate plane, which predict performance on tests of algebra achievement—a critical carry-over from previous fractional knowledge studies on the use of the number line.

Ünal et al. (2022) conducted a series of five quantitative experiments to investigate the interplay between domain-general attentional resources and domain-specific WM processes. The investigation examined both verbal and visuospatial contexts of algebraic problem-solving, extending and addressing limitations in WM as an instructional functional relationship and mechanism contributing to algebraic problem-solving by exploring the effects of cognitive load on WM's role in algebra.

Through dual-task experimental designs, Ünal et al. (2022) tested and manipulated the WM load with over 60 participants who completed algebra-relevant tasks, such as evaluating expressions and placing ordered pairs in the coordinate plane. The study's findings demonstrated that expression evaluation and coordinate plane tasks rely heavily on verbal WM, particularly under conditions of verbal load, which significantly reduces task accuracy. In contrast, arithmetic and geometry tasks exhibited less sensitivity to memory load. These outcomes support the involvement of both domain-general attention and domain-specific processes in algebraic cognition, suggesting that verbal WM plays a more critical role in algebraic reasoning than previously understood.

Importantly, Ünal et al. (2022) explicitly placed cognitive load theory, particularly as an indicator of attentional burden, within the context of dual tasks. The authors noted that the degree of task difficulty moderated the extent to which memory maintenance was compromised. For example, more demanding tasks such as mental rotation or expression evaluation significantly impaired the retention of spatial information, whereas simpler tasks had little impact. This pattern underscored the notion that performance decrements under dual-task conditions reflected increased cognitive load, especially when both the primary task and the memory load require substantial attentional resources.

In summary, Ünal et al. (2022) provided recommendations for algebraic instruction for students with mathematical LDs and MD, noting that the process of learning algebra depends on WM transfer of information and cognitive ability exertion from working to LTM, as theorized by the cognitive load theory, drawing on the works of Paas (2010), Van Merrienboer and Sweller (2005). The comprehensive set of five concurrent quantitative experiments found attention core determinants between visuospatial memory and mathematics aligned with empirical research focusing on attention as the driving factor in the relationship between WM and higher-order cognitive skills, which have necessary implications for secondary instruction. The experiments contributed to understanding WM and attentional demands of core algebraic competencies and implications for instruction. Significant to the current synthesis, the authors found notable differences between arithmetic and algebraic expressions, highlighting the need for encoding and variable value retention algebra requires through verbal working memory and spatial memory (Ünal et al., 2022).

Ünal et al.'s (2022) work had substantial implications for instructional design in mathematics education. Findings asserted reductions in unnecessary instructional tasks to reduce cognitive load, both methodologically and strategically, and manage attentional demands during instruction. Specifically, the investigators recommended instructional tasks involving verbal reasoning and variable manipulation to enhance students' ability to process and retain algebraic information. These findings provided insight into how attentional mechanisms can interact with WM to either support or hinder mathematical performance.

Building on the empirical insights from Fuchs et al. (2014) and Ünal et al. (2022), a broader theoretical perspective can be found in the *embedded process theory*, which further explores the dynamic relationship between attention and memory. This relationship has been reviewed and synthesized in alignment with the embedded process theory (See Appendix C), taken from Cowan (2001), serving as an integration of work for further theoretical understanding from Cowan et al. (2023) on the relationship between attention and memory across varied subdisciplines. Specifically, the embedded processes theory maps activated portions of the brain and described how attention and LTM interact. Environmental inputs enter an activated subset of LTM, a temporary workspace where some information moves into the FoA, a minimal capacity system controlled by abrupt or meaningful environmental changes and voluntary executive processes. The product of FoA, as part of voluntary executive processes, includes goal-oriented control, which motivations can influence. Comprehensively, the FoA knowledge acquired can be structured as chunks, transferring information back to activated LTM and eventually stored. Furthermore, primes (stimuli that activate related concepts) can influence attention with or without conscious awareness, making relevant stored knowledge more accessible (see Appendix C; Cowan et al., 2023).

Varied researchers reviewed with positive results the consequences of attention-memory relationships; effects of attention on WM and the converse, computational modeling of attention and LTM; and individual difference indicators of the effects of processing ability configurations in attention and memory as a mechanism of normal functioning versus. These individual difference indicators include cognitive load, WM capacity, and attentional control, all of which can significantly influence how individuals process and remember information (Cowan et al., 2023).

Pertinent to this present systematic review, narrowing the focus on individual differences sheds light on mechanisms of normal versus deficit processing abilities. Scenarios impacting quantitative and qualitative RQs include losing attention, causing encoding failure or poor memory retrieval, losing focus on a task, and exhibiting uninterested or inattentive behaviors. Relevant to the embedded process approach, the current research reveals that individuals with better attention control tend to keep more information in WM and excel at problem-solving and comprehension.

In summary, the authors provided recommendations for algebraic instruction for students with cognitive challenges and noted that the process of learning algebra depends on WM transference of information from WM to LTM and on exerting cognitive abilities, as theorized by the cognitive load theory. A comprehensive set of five concurrent quantitative experiments found attention core determinants between visuospatial memory and mathematics aligned with empirical research focusing on attention as the driving factor in the relationship between WM and higher-order cognitive skills, which has necessary implications for secondary instruction. The experiments contributed to understanding WM and attentional demands of core algebraic competencies and implications for instruction. Importantly, marked differences between arithmetic and algebraic expressions and graphic representations were statistically significant because they noted verbal processes in algebra in which the need to encode and retain numerical values of variables necessitated verbal working and spatial memory performance.

Since WM has limited capacity, cognitive load management is necessary to prevent overload for students with MD. Evidence suggests algebraic tasks, whether spatial (coordinate plane) or verbal (variables), place high cognitive demands even on well-educated individuals. For optimal learning, instructional strategies should minimize extraneous cognitive load and help students build fluency in fundamental skills, such as problem-solving sequences and basic arithmetic. An example included reducing the need for attention-demanding problem-solving methods, which often lead to errors. Additionally, attention allocation is crucial for concept formation, including minimizing distractions within the classroom environment. Further, Cowen et al. (2023) emphasized approaches should focus on eliminating irrelevant information, highlighting essential concepts, and linking introduced algebraic topics to previously learned mathematical areas like arithmetic and the number line, thereby drawing from fractional knowledge to ease students' cognitive load and support memory formation (Cowan et al., 2023).

Students with SLDs must develop the ability to identify numeric relationships to attain fractional knowledge. Research conducted on fractional magnitude and knowledge explored non-mathematical determinants, WM, and attentiveness as significant factors impacting the acquisition of fractional knowledge. Recommendations for instruction focused on using automaticity to reduce the fatigue-associated attentional demands of core algebraic competencies for students with SLDs, and their implications for instruction.

UDL

There are indications that UDL principles, guidelines, and considerations have an impact on WM. The terms checkpoints and considerations will be used interchangeably, reflecting how they are documented in research across both UDL 2.0 and the updated UDL 3.0 framework, as reviewed in the empirical literature. Thus, UDL checkpoints and considerations were interchangeable to ensure that terminology representations from research studies were accurately represented and synthesized for significance and implications to the review.

UDL is an instructional framework based on three core principles: multiple means of engagement, representation, and action and expression. Developed by CAST in 1984, UDL aims to support inclusive education by offering flexible approaches that accommodate all learners' diverse strengths, abilities, and interests, particularly those with disabilities (CAST, 2021). Grounded in cognitive and psychological research, UDL aligns with the brain's three primary neural networks: the affective system (engagement), the recognition system (representation), and the strategic system (action and expression). The most recent version of the UDL Guidelines, Version 3.0, has been reviewed and applied in this study. This updated iteration builds upon CAST's (2021) prior empirical research and incorporates expanded pedagogical approaches grounded in learning and disability studies. These guidelines emphasize learner variability and promote instructional flexibility to improve literacy outcomes, increase student engagement, and enhance content-area learning. They also offer educators a structured set of considerations and strategies designed to support the development of inclusive and responsive instructional practices.

The literature review specifically examined empirical studies exploring the connection between UDL principles and WM in mathematics instruction for students with SLDs in secondary education settings. The designers of UDL Guideline 6—Strategy Development (Version 3.0)—emphasize that a key aspect of learning is the ability to act with skill and purpose, known as executive functioning. These functions, managed by strategic networks in the prefrontal cortex, influence how someone processes emotions, recognizes information, responds to their environment, and sets and pursues long-term goals. According to CAST (2024), effective learners use strategies like monitoring their progress and adjusting their approach as needed, making purposeful use of available tools and resources. Since executive function is closely tied to WM and focused attention, CAST's (2024) UDL framework aligns with activating learning through executive functioning in the following manner:

> The UDL framework typically involves efforts to expand executive capacity in two ways: 1) by scaffolding lower-level skills so they require less executive processing; and 2) by scaffolding higher level executive skills and strategies so they are more effective and developed. Previous guidelines have addressed accessibility supports and scaffolding. This guideline addresses ways to provide scaffolding for executive functions themselves. (CAST, 2024, para. 1)

In referencing Cowan et al.'s (2023) finding of the relationship between attention and memory, CAST's (2024) UDL framework addresses aspects of the embedded processes theory, in which the prefrontal cortex, the area of the brain responsible for processing information through memory and recognition, activates attention and LTM interactions (CAST, 2024a). Environmental stimuli entering the activated subset of LTM, where information moves into the FoA as part of the executive process, theoretically produces a voluntary executive process, including goal orientation and storage of related information (Cowan et al., 2023). These theoretical correlates between UDL and its impact on executive functioning for student learner agency in secondary mathematics dictate further exploration.

Reid et al.'s (2017) study on cognitive behavior therapy and the necessary application of an inclusive framework embedded in an active instructional delivery model for psychotherapeutic methods references UDL's application to Part 1 of three of the brain's networks. Meyer et al. (2014) asserted that it impacts students' ability to learn. Reid associated the brain's strategic network as utilizing acquired knowledge or demonstrating what students have learned by connecting this to UDL's principle of providing multiple means of action and expression. Specifically, Meyer et al. (2014), stated that "the strategic network represents how one utilizes acquired knowledge or demonstrates what has been learned" (Reid et al., 2017, p. 83). This network corresponds with the action and expression principle, a key aspect of UDL that supports and enhances learning by allowing learners to use acquired knowledge effectively (Meyer et al., 2014). The summary of UDL further breaks down this principle into supporting physical action, expression, communication, and executive function. In the study, corresponding checkpoints were defined from UDL Version 2.2 for executive function in the scope of poor executive functioning skills (e.g., losing worksheets, forgetting) as a determinant for identifying possible barriers that impact learning. Reid et al. (2017) applied the UDL Version 2.2's multiple means of action and expression principle to provide options for executive functions applicable for students with self-regulation challenges, noting to clinicians the need to integrate executive functioning needs such as planning, organizing, monitoring, and setting appropriate goals for their caseload patients. These components of the UDL 2.2 checkpoints guided management information, resources, and progress monitoring. A significant example included clinicians helping students plan out steps to master a specific skill rather than exhibit complete mastery after one session, thus recognizing the importance of the patient's individualized planning and programmatic application. The clinician and patient could work together to develop and implement the plan, with progress monitoring checks and balances designed by the student. The descriptive study provided a basis for further research into the action and expression principle's connection as a mechanism of executive functioning and activation of WM through central executive functioning (Reid et al., 2017).

Gravel (2018) conducted a qualitative case study on the application of UDL in a 10-week English language arts (ELA) session to investigate how UDL can support deep disciplinary thinking. A central problem identified throughout the study was UDL's broad applicability across educational contexts, which addressed the lack of specificity of checkpoints and guidelines when applied within distinct disciplines such as ELA. The study, conducted in an urban, full-inclusion 10th-grade classroom where 30% of students received special education services, was reflective and provided feedback toward refining UDL 2.0 for added disciplinary specificity and checkpoint-intensive capability. The author utilized multiple data sources, including classroom observations, student work, teacher interviews, and artifacts. Coding was applied consistently throughout the analysis using UDL "etic" codes and disciplinary thinking matrices. Gravel (2018) acknowledged potential subjectivity due to her affiliation with CAST (2011), which developed UDL. A key focus was on UDL Version 2.2 Guideline 6—Provide

Options for Executive Functions—and how it supports planning, organization, and revision when grounded in content-specific practices like *writing like a writer*. Particularly significant was the role of UDL's action and expression principle in activating executive functioning in students with disabilities. Also significant was the acknowledgment of multiple means of action and expression that activate executive functioning in students with disabilities.

Further studies from Meyer et al. (2014) and Reid et al. (2017) asserted that the UDL action and expression principle leads learners to effectively use acquired knowledge; thus, it plays a pivotal role in transferability to what is learned and applied in daily life (Meyer et al., 2014; Reid et al., 2017). The study highlights UDL's promise to develop strategic learning networks and support diverse learners through increased specificity embedded in instruction. Specifically for purposes of the literature reviewed, emphasis on the UDL action and expression principle and its connection to the brain's executive functioning is significant despite noted limitations in the specificity of station activities and lack of direct empirical connection to long-term strategic use.

Root et al. (2020) conducted a single-subject, multi-probe design study to evaluate the effectiveness of a universally designed mathematics intervention for middle school students with extensive support needs (ESN), particularly those with executive functioning and self-regulation challenges. The intervention utilized modified schema-based instruction (MSBI) grounded in UDL principles that emphasized multiple means of action and expression. The study aimed to determine whether embedding UDL principles into MSBI would improve students' ability to solve multi-step word problems, including real-world scenarios such as calculating tips and store discounts. Two RQs guided the study: (1) whether a functional relation exists between the intervention and improved mathematical problem-solving skills, and (2) whether those effects generalize to novel, non-monetary problems.

Using three experimental conditions, baseline, intervention, and generalization, Root et al. (2020) analyzed performance across three instructional phases (% increase, % decrease, and discrimination). A three-session probe between phases assessed maintenance. All participants began in the baseline condition simultaneously; they progressed through phases at their own pace upon meeting performance criteria. To support the executive functioning needs of students with ESN, students learned how to self-monitor using the task analysis (TA; Consideration 6.3). Interventionists used the think-aloud to model strategy employment (Consideration 6.2). The investigators identified components of the UDL action and expression principle in options for executive functions, specifically TAs, instructor think-aloud, and goal setting as a guide for student goal setting. Results showed an immediate improvement in participants' problem-solving performance following the intervention, with no overlap in baseline and intervention data. Visual analysis confirmed a functional relationship between the UDL-based MSBI intervention and enhanced ability to solve complex, two-step mathematical problems (Root et al., 2020).

In summary, the significance of UDL as an intensive intervention includes activating SLD students' WM and maintaining alertness throughout the instruction cycle in mathematics. Almeqdad et al.'s (2023) quantitative systematic meta-analysis of UDL implementation in the educational setting showed that UDL's application of its principles underscores the importance of supporting executive functioning interventions to support student engagement across content disciplines, including mathematics (Almeqdad et al., 2023). Analyses revealed that the effect of verbal memory load on geometry tasks had a positive effect, hypothesizing possible reasoning due to geometry tasks making little demand on WM in the presence of a memory task, and maintaining student engagement and alertness. According to Davies and Parasuraman (1982), maintaining alertness continually during tedious tasks is considered a basic quality of the ability to sustain alertness through selective attention and abrupt environmental changes. In summary, UDL action and expression considerations could serve as components of the embedded processes theory. They may function as prime stimuli that activate related concepts for intensive instructional intervention, or as meaningful environmental stimuli that elicit voluntary executive processes. These functions could occur through lesson relevance, drawing connections, offering student choice, and fostering motivation—thereby supporting the creation of LTM connections and aligning goals with tasks as an attentive mechanism.

Conclusions

The purpose of this systematic literature review was to examine predictors of success in algebra, the challenges experienced by students with SLDs in secondary mathematics, and the effectiveness of the UDL action and expression principle in supporting executive functioning—particularly WM—during math instruction. Three key RQs guided the review:

1. What skill sets are fundamental as a predictor of success in algebra and subsequent secondary mathematics?
2. What are the challenges that students with SLDs encounter in secondary mathematics, and how do these challenges impact their learning?
3. Is there a functional relationship between implementing the UDL action and expression principle to activate WM through executive functioning to attend to math instruction?

Predictors of Algebra Success: Fractional Knowledge and Attentive Behavior-Memory Retrieval

The first RQ sought to answer what foundational skill sets predict success in algebra. Across studies, fraction magnitude understanding consistently emerged as a critical predictor. Booth and Newton (2012) and DeWolf et al. (2015) demonstrated that visual and conceptual fraction magnitude models enable students to develop the abstract reasoning skills necessary for algebra. The dual nature of fractions—as both part-whole relationships and representations of division—mirrors the symbolic structure of algebraic expressions. DeWolf et al. (2015) emphasized that drawing connections between fractions and algebra supports the development of mathematical reasoning and symbolic fluency. Ching (2024) further argued that students who develop a relational understanding of fractions can better generalize patterns, such as expressing proportional relationships in equations like $3x = y$. This ability to extend understanding from one domain to another reflects higher-order mathematical thinking.

Fuchs et al. (2014) conducted a quantitative study to explore how WM moderates the effects of fraction interventions among students with and without LDs. Their study compared fluency-based and conceptually focused instruction as an intervention and revealed that students with lower WM capacity showed greater gains when provided with conceptually rich instruction. These findings suggest that fraction understanding is not merely a matter of procedural fluency but intricately related to students' cognitive capacities, particularly WM. As students measured and interpreted fractional magnitudes, such as part-whole relationships, equivalence, and proportional reasoning, they relied heavily on cognitive processes tied to the central executive system, including attention control, information processing, and conceptual flexibility. Although the study did not assert that WM strengthened fraction learning, it emphasized the foundational role that WM plays in enabling students to construct and apply conceptual knowledge of fractions. Thus, this element highlighted the co-dependent relationship between (a) SLD students' ability to measure and accurately interpret fractions, and (b) engage in higher-order conceptual processing influenced by their WM capacity and processing speed. Fraction measurement was depicted as being not an isolated skill but as requiring sustained mental effort supported by executive functioning.

These findings underscored the importance of designing math instruction that accounts for individual differences in cognitive profiles. Results of the investigation specifically noted the role interventions have in reducing cognitive load through scaffolded tools to elicit students' conceptual understanding through visual models, strategic pacing, and guided problem-solving, which could provide the necessary support for students with lower WM to access and apply fractional concepts successfully. Thus, WM emerged as critical in the fractional learning process because it shapes how students can potentially interact with and internalize the foundational elements of algebra through fraction magnitude reasoning.

Challenges for Students With SLDs: Memory, Attention, Cognitive Load

The second RQ focused on the specific cognitive and instructional challenges students with SLDs face in secondary mathematics. One of the most significant issues identified was cognitive overload. As noted previously in Fuchs et al.'s (2014) empirical study, as students measure and interpret fractional magnitudes, such as part-whole relationships, equivalence, and proportional reasoning, they rely heavily on cognitive processes tied to the central executive system, including attention control, information processing, and conceptual flexibility, which stresses cognitive load considerations on processing speed and has a negative impact on students with SLDs when working through mathematic instruction. Cowan et al. (2023) contributed to understanding cognitive load management and its implications for potential overload for students with SLDs experiencing MD. They stressed the importance of instructional interventions strategically reducing high cognitive demands to facilitate students with SLDs building mathematical fluency, such as multi-step problem-solving and sustained attention to instruction. Further, they emphasized that students with SLDs risk potential vulnerability to high cognitive load during mathematical tasks, thereby potentially limiting fluency, accuracy, and motivation. The study's recommendations highlighted the importance of instructional strategies to reduce high cognitive demands on students with SLDs as learners so that their focus might be on specific core concepts—through tailored instructional intervention such as scaffolding and explicit modeling—to address the challenges in the study.

UDL: Action and Expression

The third RQ examined how the UDL action and expression principle can support students' WM and executive functioning during mathematics instruction. While UDL does not directly activate WM in a neurological sense, it provides structured support to reduce cognitive load and enhance students' capacity to engage in complex tasks. CAST developed the UDL framework to promote inclusive learning environments. The UDL action and expression principle emphasized providing learners multiple options for demonstrating knowledge, thereby removing barriers to planning, organizing, and motor execution (CAST, 2024a). This assertion supported students gaining access and engagement through WM by externalizing complex processes through tools such as manipulatives, visuals, and assistive technologies. Reid et al. (2017) linked UDL's action and expression principle to the brain's strategic network, which governs executive functions like goal setting, planning, and self-monitoring. Reid et al. (2017) affirmed that components of action and expression supported students' planning, organizing, and monitoring by setting goals when processing and applying information. Similarly, Gravel (2018) and Root et al. (2020) affirmed that using action and expression strategies can help activate executive functioning by offering explicit opportunities for students to plan, organize, and monitor their learning processes.

Research shows that strong fraction magnitude knowledge gives students with SLDs a bridge from concrete quantities to the abstract, relational thinking needed for algebra. By grasping how numerators and denominators interact multiplicatively, learners sharpen proportional reasoning, establish pattern recognition, and gain an intuitive sense of number size, all of which are cornerstones of later algebraic work. Acquiring these skills, however, depends on more than math instruction alone.

Studies also highlighted WM capacity, sustained attention, and automaticity as critical, non-mathematical determinants of fractional understanding for students with SLDs. When the cognitive load is reduced, there is a higher likelihood of sustained engagement, suggesting that well-designed tasks can free WM and allow the student to maintain attention to instruction. These findings align with UDL principles calling for instruction that activates WM and maintains alertness throughout a lesson. Embedding prime stimuli—relevant visuals, choices, or connections to students' goals—can trigger executive processes and make abstract fraction relationships stick. In short, fraction magnitude work, supported by strategic UDL-informed scaffolds, lays a robust cognitive and motivational foundation for students with SLDs as they progress toward algebra.

Significance

Recommendations for Research

Based on the reviewed literature, the UDL action and expression principle can serve as a mechanism to support WM and increase attentiveness, which in turn can enhance fraction magnitude learning, understanding, and application, particularly for students with SLDs. Although UDL designers and applied research do not claim to activate WM directly, empirical research has shown that UDL offers structured support to reduce cognitive load in mathematics. When applied as an intensive intervention embedded in teaching practices, this support can significantly improve fraction learning. However, additional research on UDL through action and expression, and on how it impacts the process of SLD students' fractional knowledge acquisition, and on its dependency on executive functioning through WM and attention to instruction is necessary for academic accessibility through supports that increase processing speed to engage in academic tasks like fraction learning.

Recommendations for Practice

The literature review that was synthesized included quantitative, qualitative, and mixed-methods research to statistically support identifying key skill sets, such as problem-solving, critical thinking, and mathematical reasoning, that predict success for students with SLDs. Based on the review conducted, determining connections of acquiring key skill sets from the literature and identifying what executive functioning is necessary to acquire and retain such skill set predictors answered deficits in the research. Finite predictors were identified across empirical research reviews and validated findings. The synthesis also highlighted the role of a universal design framework that can serve as a WM procedure for effective instructional interventions to build skill set predictors for algebraic success. Empirical research identified through reference list review served as a historical basis for understanding the causes of MD for students with SLDs pertinent to current research and product development, thereby contributing to the importance of identifying and shaping the synthesis review.

This study also investigated the application of UDL, a framework of evidence-based teaching practices aligned with brain-based learning principles, to inform instructional strategy development for secondary students with SLDs in mathematics and students identified with MD through assessment measures. By emphasizing the UDL action and expression principle, specifically Guideline 6—Strategy Development along with Considerations; 6.1—Set Meaningful Goals; 6.2—Anticipate and Plan for Challenges; and 6.3—Organize Information and Resources, the study next explores underlying causes of algebraic reasoning deficits and the design of a universally accessible intensive intervention. Grounded in a critical review of existing research and the updated UDL 3.0 framework from CAST, the study evaluates the potential of UDL principles to address learning variability and reduce performance disparities among students with specific learning needs in mathematics. Rather than presuming effectiveness, the review will assess how UDL guidelines can ameliorate math performance disparities for students with specific learning needs (CAST, 2021).

Limitations of the Research

Empirical researchers note challenges in testing UDL as an instructional intervention due to its organic and adaptable nature. A significant limitation is the lack of an agreed-upon operationalization of UDL across empirical studies to meet evidence-based criteria. Given the limitations of existing empirical and descriptive studies, researchers face challenges in conducting empirically tested interventions to assess effectiveness.

Historic empirical and descriptive studies have noted increased attitudes, beliefs, and self-efficacy and have used UDL principles through alternate interventions. Thus, while positive results have been attributed to UDL, the evidence has not been definitive on UDL's efficacy. King-Sears et al. (2022) recommended greater clarity when operationalizing UDL to enable researchers and practitioners to receive transparent information about the design of interventions and learner outcomes (King-Sears et al., 2022).

Further limitations emerged during the review of empirical research from the CAST (2024) studies referenced, which informed guidelines and considerations for this study. CAST (2024) cited references that indicated a lack of empirical cross-sectional studies on UDL implications (CAST, 2024a). In addition, challenges remain in empirical research examining mechanisms of executive functioning (e.g., working memory and central executive processes) in relation to fractional knowledge and higher-level mathematics skills, such as algebra. Intersections between central executive functioning, mathematics, and students with SLD are linear, yet empirical research has not yet aligned on or measured these areas over time. Finally, empirical research limitations are especially evident when considering high-quality and validity standards. Minimal studies underscore the need for more methodologically sound research to increase the evidence base for UDL as an empirically valid intervention for students with SLDs in secondary mathematics.

SECTION 3: A PLAN

The literature review analyzed empirical and descriptive studies that support the establishment of a universally designed model through the UDL action and expression principle's Guideline 6—Strategy Development. A narrow focus on Guideline 6, specifically Consideration 6.1—Set Meaningful Goals, 6.2—Anticipate and Plan for Challenges, and 6.3—Organize Information and Resources, was explored in-depth for the delivery of intensive instruction to students with SLDs (CAST, 2024a). An intensive review of the literature led to the design of a product for practitioners, developed as a Math and Working Memory (MWM) Design Tool lesson plan template. This template is grounded in evidence from the literature demonstrating the potential for a targeted intervention with a focused approach that serves to improve SLD students' performance in algebra. The developed product includes PD for practitioners. The focus is on secondary educator practitioners, specifically those in middle grades, where mathematical standards align with fractional knowledge, which serves as a basis for acquiring algebraic skills in higher secondary math areas at the high school level.

PD includes the implementation and delivery phases of the product. Existing empirical evidence on the use of classroom interventions notes that the routine use of intensive interventions within the general education classroom remains a challenge for teachers. Traditionally, teachers often lack the knowledge and education to utilize instructional interventions such as UDL. Lambert et al. (2021) asserted that factors contributing to underperformance among secondary students with SLDs in the math classroom include the teacher's skill set or lack of knowledge in utilizing inclusive instruction (Lambert et al., 2021). Additionally, teachers often struggle to identify effective instructional methodologies to reach middle-grade students with SLDs in mathematics (Soares et al., 2018). Finally, accurate and aligned use of the lesson plan tool requires PD tailored to each component of the UDL WM lesson template. Common alignment for teacher participants supports the assessment phase of product designers to determine the effectiveness of PD and product efficacy.

UDL and WM: Theoretical and Practical Integration

UDL provides a framework that supports diverse learners by reducing barriers and promoting accessibility through multiple means of engagement, representation, and action and expression. According to CAST (2025), components of the UDL action and expression principle increase attentiveness and cognitive engagement and align with Baddeley's (1999) multicomponent model of WM. Specifically, Guideline 6—Strategy Development emphasizes executive functioning capacity by targeting the strategic networks of the prefrontal cortex and interconnected regions of the brain involved in recognition. This recognition process engages the brain's strategic networks, allowing students to become intentional in their short-term responses to both their environment and their learning goals and to ultimately develop strategies to attain those goals (CAST, 2025). Guideline 6 also supports reducing cognitive load for students by implementing scaffolding mechanisms designed to expand executive capacity, thus minimizing the executive processing required during instruction (CAST, 2025). Although UDL's action and expression principle does not biologically activate WM, it provides external scaffolds and cognitive support that significantly reduce extraneous cognitive load. Internal instructional support helps minimize cognitive demand, increase WM efficiency, and enhances students' ability to apply their existing WM capacity to complex tasks, such as interpreting the magnitudes of fractions.

Research by Fuchs et al. (2014) reinforced this connection, revealing that WM is a critical moderator in how students respond to different instructional approaches in mathematics, particularly in learning fractions highlighting WM's role in supporting students' ability to interpret and manipulate fraction magnitudes, especially among those with LDs in mathematics. Significant to the plan and product development, students with lower WM performed better when provided with conceptual instruction as opposed to procedural approaches, thus highlighting the importance of intentional instructional design that supports cognitive processing.

Math and WM UDL Lesson Design

To translate these findings into classroom practice, educators can use tools grounded in UDL's action and expression principle to guide and support learners. One such tool, the MWM Design Tool lesson template, is a teacher and student-led instructional template designed to help students clarify their goals, identify areas of struggle, and visually model mathematical concepts. The organizer includes prompts such as the standard addressed in student-friendly language, the SLD students' goals stated in their own words, a self-identified area of difficulty, a modeled math problem with an explanation, a student-created math problem, guiding questions to support thinking, and a second practice problem to reinforce learning. The MWM tool can enhance and provide access to mathematics instruction for students with disabilities at the individual level. At the same time, its UDL-scaffolded process provides the necessary support for struggling learners who face attentional challenges or overall math difficulties, with or without disabilities. The MWM Design Tool supports metacognition, provides multiple entry points into mathematical understanding, and fosters strategic thinking for students with SLDs. Ultimately, the goal of UDL is to nurture expert learners—students who are purposeful, motivated, resourceful, and strategic in their approach. The use of scaffolds such as the MWM Design Tool contributes to gaining learner agency, which helps students progress along a continuum from guided to independent learning. Through thoughtful integration of cognitive science and UDL practices, educators can support all students in developing the skills they need to become autonomous and effective learners.

Activity Rationale: Understanding Fractions on a Number Line

Fuchs et al. (2014) noted the importance of formal instruction rather than educators presumptively relying on students intuitively gaining an understanding of measurement interpretation, which requires explicit instruction on symbolic notation. Instruction that is intentional and detailed should serve to build a deeper understanding of fraction measure concepts in students with SLDs, such as the inversion properties of fractions, so that they might gain an understanding of measurement and interpretation of fractions related to cognitive processes, especially WM. Isolated steps include goal setting/identifying what they want to solve, and the challenge associated with solving, use of student language, conceptualization of math problem, and identification of what they want to do when solving a problem in isolation integrates the UDL action and expression principle and serves to reduce cognitive load. Booth and Newton (2012) and DeWolf et al. (2015) both demonstrated that understanding of fraction magnitude predicts later algebra success. Importantly, visual and conceptual models help students transition to abstract thinking.

Instructional Learning Design

The MWM Design Tool implementation follows a structured instructional process that begins with professional learning, progresses through the PLAN framework (discussed below), and extends into a long-term assessment, monitoring, and collaborative phase (see Figure 1).

Figure 1

MWM Design Tool Implementation Framework

Professional Learning Course (15 hours)
- University Credit Option
- Based on UDL Action and Expression (6.1, 6.2, 6.3)

↓

Professional Learning Pathway
- Session 1: Pre-Work (Online)
- Session 2: Face-to-Face Collaboration
- Session 3: Assessment and Implementation Monitoring

↓

Ongoing Expansion
- Year 1: Progress Monitoring
- Year 2: Teacher Rounds & MWM Implementation

The framework illustrates the instructional learning course, PLAN framework, PD pathway, and ongoing support and expansion. The instructional learning course, divided into multiple sessions, is a professional learning experience that offers participants the option to earn course credit hours through an accredited university. The objective of the course is to shift teacher attitudes and beliefs toward lessons that actively engage students with SLDs in the mathematics classroom. To achieve this outcome, the course will center on the instructional learning cycle of teaching educators both how to use the MWM Design Tool and why the tool is practical. Educators will explore each component of the MWM design as an intensive intervention to embed in instruction rooted in the UDL action and expression principles, specifically Considerations 6.1 through 6.3, which emphasize goal setting, strategic planning, and progress monitoring.

Professional Learning

Product developers will design professional learning for teachers to build teacher agency and effective implementation of the MWM Design Tool. Reviewed research hypothesizes the benefits of professional learning for educators. Professional learning influences teacher behaviors or willingness to engage in executing inclusive teaching practices. For example, quantitative quasi-experimental research from Baldiris Navarro et al. (2016) and Spooner et al. (2007) studied the effects of PD in UDL on lesson plan development (Baldiris Navarro et al., 2016; Spooner et al., 2007). In a mixed-methods study, Smith-Canter et al. (2017) noted the challenges of delayed paradigm approaches to education, which can directly impact how students learn and teachers teach. Their study also aimed to assess the effectiveness of UDL PD in the classroom.

The Spektor-Levy and Yifrach (2017) mixed-methods research design study investigated teacher behavior in inclusive practice. Using the theory of planned behavior model, researchers tested the perceptions and intentions of teachers regarding teaching learning-impaired students in general education. Experts conducted a validity and reliability assessment of the test instruments and achieved an agreement of 85% to 95% on the finding that teachers' attitudes significantly contributed to their behavioral intent. Results showed that professional learning was a significant influence on teachers' willingness to adopt diverse teaching methods (Spektor-Levy & Yifrach, 2017). Research by Griful-Freixenet and colleagues (2020, 2021) aimed to develop a multivariate prediction model for UDL actions, with main predictors including growth self-efficacy to promote inclusion, self-regulation, and motivation for teaching. The study successfully identified correlates in predicting teachers' beliefs, self-efficacy, and growth mindset, which facilitated the implementation of an inclusive education model (Griful-Freixenet et al., 2020, 2021). In sum, cumulative research findings demonstrate that PD models are predictors of shifting teacher self-efficacy and the development of a growth mindset when learning inclusive instructional models such as UDL.

Coursework for the PD will consist of in-person learning over one semester. Timelines for the course include an initial offering in fall 2026 that provides foundational concepts of UDL alongside a targeted application of the lesson template. The objective of using the lesson template is to support educators in creating lessons that cater to diverse learning needs, thereby making it a practical and relevant resource for student learning, specifically in developing fractional knowledge. Participants will begin by being introduced to components of the MWM Design Tool, which will include an abbreviated but tightly aligned acronym called PLAN to cue teachers in supporting students with planning, organizing, expressing, and monitoring their own learning, key components of the UDL action and expression principle, specifically Considerations 6.1 through 6.3:

- P (Plan/Set Goals)—helping students set individual goals.
- L (Limit Cognitive Load)—reducing steps and providing a model.
- A (Allow Multiple Means of Expression)—incorporating visuals and writing.
- N (Nurture Reflection and Agency)—nurturing self-monitoring and encouraging reflection, self-checklists, and peer or teacher-student feedback through partnership.

The target audience includes secondary mathematics educators who teach middle-grade math teachers, including pre-algebra. Within this target audience, middle school-aged students served should benefit from a lesson template of this nature because it is an easily integrated tool to design instruction that engages students in abstract thinking, goal setting, and self-identification of challenge areas, thereby supporting learner agency in developing fraction magnitude skills. By participating, educators will deepen their understanding of UDL applications in mathematics instruction and develop strategies that promote WM activation, decrease cognitive load, and facilitate engagement for students with SLDs or learning difficulties.

State Education Agency Authorization

Product implementation begins by using state or regional education agency leadership approval processes to propose instructional learning coursework within state education agencies and affiliated local school systems. The proposal process ensures that instructional development aligns with instructional priorities and student achievement goals. The purpose of this process is to provide standardized, transparent guidance for the submission, review, and authorization of credit-bearing coursework facilitated by educational personnel.

This process applies broadly to instructional leaders at the state, regional, and local education agency levels, as well as to education agency administrators and instructional development coordinators. Instructional learning proposals must demonstrate explicit alignment with established state and local educational initiatives and serve to enhance the quality of school improvement and ultimately lead to increased student achievement. Components of the instructional learning proposal should include how individual school action plans will be targeted and grounded in addressing comprehensive student performance measures through instructional strategies and expected outcomes.

Primary submission requirements can include:

- Documentation of alignment with state, regional, district, and school improvement plans.
- A specified target audience.

- Clearly articulated course outcomes and instructional objectives tied to measurable learning improvement.
- A timeline for course delivery and implementation.
- Identification of course facilitators or instructors.
- Accreditation and credit-hour information from the associated college or university as appropriate.
- A complete course syllabus and description (with a minimum of 15 hours of work required per university credit hour).
- A formal chain of approval, including signatures and recommendations from supervisors at the school, district, and regional levels, culminating in review by an appointed panel.

Review panels—typically composed of representatives from instructional leadership and each district—convene quarterly to evaluate submissions and maintain a database of approved proposals and feedback. Subject matter experts, such as math instruction coaches, may be consulted to support reviews of specialized coursework. Instructional learning plan decisions by designated leadership at the state or regional level ensure a structured process that certifies the instructional learning activity meets rigorous common-core standards, aligns with strategic educational initiatives, and contributes meaningfully to teaching effectiveness and student performance.

Instructional Learning Activities and Intended Outcomes

The in-service will consist of structured modules with a clear outline and interactive activities that incorporate UDL action and expression strategies to activate WM. Instructional learning will focus on emphasizing the importance of fractions in building algebra readiness and helping participants identify key academic standards that support the development of fraction knowledge and magnitude skills essential for future mathematical success. Instructional learning activities, scheduled on a quarterly timetable, will consist of three-tiered, interactive sessions. Sessions will include an introduction to UDL, followed by deeper, relevant dives into the action and expression principle and its connection to research for the purpose of targeting the activation of WM and its application to mathematics. Activities will lead to a formalized use of a lesson design template to guide teacher and student goals and the instructional process.

Furthermore, sessions will guide and enable teachers to make paradigm shifts in their instructional practice through practical application over a more extended period by utilizing peer collaboration and assessment cycles to effectively support students with SLDs by addressing WM challenges and implementing strategies to reduce cognitive load. Use of school personnel resources will create additional collaboration opportunities—known as instructional resource planning time—within the master schedule. Collaboration time within the school day includes using substitute teachers for participating educators, utilizing shared planning time, and employing instructional specialists as a resource. Specialized planning for participants is an alternate plan for collaboration opportunities facilitated through local school administration. In the instructional learning timeline, as shown in Table 1, Year 1, professional learning activities will follow a quarterly schedule, starting in September 2026 with pre-work and continuing with progress monitoring from December 2026 through June 2027. Year 2 progress monitoring activities will include teacher rounds and continued implementation of the MWM Design Tool intensive intervention support in the general education math classroom. The UDL-based instructional learning cycle should align with the local school system's continuous school improvement activities to include committed data review of student assessment data, participant metrics for quality assurance, trend data to inform subsequent sessions, and scheduling follow-up actions to ensure progress and accountability among departmental collaboration teams. The intended outcomes are to deepen teacher understanding of the foundational role of fractions in mathematics, enhance the use of research-based strategies to support students with learning differences, and promote consistent, data-informed instructional improvement through structured follow-up and feedback cycles.

Table 1

Year 1 and Year 2 Professional Learning and MWM Design Tool Implementation Timeline

Year	Month(s)	Session	Description
1	September 2026	Session 1	Pre-work
1	October 2026	Session 2	Face-to-face professional learning
1	November 2026–June 2027	Session 3	Progress monitoring
2	September 2027–June 2028	Session 4	Teacher rounds and MWM Design Tool

Professional learning activities include implementation of the MWM Design Tool, along with qualitative and quantitative assessment using the Professional Learning Rubric and MWM Design Tool Implementation Fidelity data collection. The target audience includes secondary math teachers, specifically those in middle grades and algebra disciplines.

Instructional Learning Course Summary

This instructional learning course will equip educators with the skills to apply UDL in mathematics. Embedded within the learning cycles will be a focus on fractions as a bridge to algebra. The course will teach the significance of UDL, highlighting how students experience math differently and how UDL strategies provide multiple entry points to support all learners, particularly those with challenges. Course components will be divided into three sessions, including asynchronous pre-work to provide background knowledge of UDL principles. The sessions will target the action and expression principle's strategy development guideline, emphasizing Considerations 6.1—Set Meaningful Goals, 6.2—Anticipate and Plan for Challenges, and 6.3—Organize Information and Resources.

Session 1: Online Module—Pre-Work

Session 1, with four sections, will engage participants in components of UDL Consideration 6.1 through 6.3 as a teaching model for teachers to learn to apply to their classroom lesson design, listed by objective. Beginning with Section 1, teachers will delve deeply into UDL and apply it directly to identified focus areas based on student performance measures and data analysis. One component of the course focuses on introducing the UDL framework and emphasizing action and expression, which is applicable through math and WM mechanisms. Activities grounded in math and WM include readings, videos, and examples of flexible ways students can demonstrate understanding. Moreover, plausible indicators of reduced cognitive load and activated WM serve as the basis of the learning. Product developers will seek models of math and WM that are embedded with universally designed methodologies to build connections for participants. Reflection activities guide participants in connecting new learning to their students and committing to measurable next steps through a lesson design template.

Session 2: Face-to-Face Collaboration

In Session 2, teachers engage in face-to-face collaboration, applying UDL strategies to targeted content-specific fraction knowledge, including discussions on how UDL reduces cognitive load, supports WM, and fosters conceptual understanding. Session objectives include identifying the role of WM in fractional learning and applying the UDL Considerations 6.1, 6.2, and 6.3 as scaffolded tools for both teacher lesson implementation and fostering student learner agency. The UDL WM lesson template, named PLAN, is memorable and easy for practitioners to use to connect UDL to WM strategies. In the following paragraphs, PLAN is described and categorized by its acronym and explained in-depth to facilitate participant understanding and application.

First, the **P** in PLAN is designed to help students plan (or set) individual goals by describing the lesson objective through a student-stated goal grounded in Consideration 6.1—Set Meaningful Goals. Teachers begin the lesson by working with students on developing their stated goal once the introduction component fraction type is initiated, and students begin the practice stages of learning. Student-stated goals support the finding from Fuchs et al. (2014) of students enhancing a conceptual understanding of the *why* of math concepts by stating their learning goals and self-expected outcomes. These steps reinforce their understanding of the task, identify their challenges, and support students with lower WM, which is significant for students with SLDs (Fuchs et al., 2014). Then, students identify their challenges in the section "My Area of Struggle" based on Considerations 6.2 and 6.3, which assert that learners navigate the learning environment in varied ways and must identify or anticipate challenges to develop learning goals as part of an improvement plan (CAST, 2024a).

Moreover, product development also includes Consideration 6.2—Anticipate and Plan for Challenges, which has the expressed purpose of the student learner devising their own plan when broaching how best to learn the respective faction set during the exercise. Steps for the student include organizing their own thoughts, hypothesizing how they will solve the problem, and personally identifying what they need to know and what they do not understand in order to plan for challenges. These steps enable students to strategically plan and utilize their teacher as a coach in thinking and modeling the required processes necessary to solve the presented problem. The learner anticipating and planning for challenges scaffolds the learning as a step-by-step process, thereby reducing cognitive load and activating WM by identifying what they know and relating it to their prior knowledge, which helps them carry out their task.

Second, the model math problem based on UDL Considerations 6.2 and 6.3 includes student learners showing and explaining their work by using only one problem to reduce cognitive overload and simplify student and teacher assessing progress under the Visual Model section. The **L**—limiting cognitive load—is supported by providing models, reducing steps, and chunking tasks. Transitioning to the Step-by-Step Explanation section enables subsequent feedback from both student and teacher. This joint progress monitoring is clear, timely, and informative, and it strengthens learner agency throughout the process. It also integrates Consideration 6.3—Organize Information and Resources—by structuring information and supports as a conceptual learning tool. In doing so, it supports knowledge development and problem-solving and builds (WM) through organizational aids that make the "how" and "why" explicit, deepening conceptual understanding. As noted in the NMAP (2008) report, students' conceptual understanding of the foundational skills in math is noted as critical for understanding mathematics in SLD students' respective grade levels.

Third, the Your Turn: Student Math Problem section provides students with visual and writing opportunities to apply their learning through a scaffolded approach, incorporating levels of inquiry that are grounded in UDL Consideration 6.3. The **A** allows for multiple means of expression and facilitates students using the Key Questions While Solving section to organize information and visually utilize an active checklist and note-taking annotation as they work through the problem-solving process.

The problem-solving process incorporates the fourth component of the acronym—**N** for nurturing—across many steps. The **N** component nurtures self-monitoring by encouraging reflection, using self-checklists, and fostering feedback through peer or teacher-student partnerships. In addition, **N** represents nurturing learner agency, which helps students reflect and build their capacity to develop their own strategies. Through this process, students not only strengthen retention of key components of the NU framework, particularly fractional magnitude as a foundation for fractional knowledge, but also develop social and emotional learning skills. These skills include greater self-awareness, perseverance, and confidence in problem-solving, as well as relationship skills fostered through collaboration and feedback exchanges.

In Session 2, secondary math educators will engage in a full day of professional learning training that covers the UDL-based MWM Design Tool. The day's activities will include follow-up pre-work on UDL and focusing on the application of UDL using action and expression guidelines. Specifically, educators will learn to apply UDL scaffolding strategies to build fractional knowledge through intensive intervention-based instruction by focusing on reducing cognitive load and supporting WM. Implemented interventions built into the MWM Design Tool will support building conceptual understanding for students with SLDs. The session introduces the PLAN lesson template, which connects UDL principles to practical classroom strategies and helps students develop agency in their learning.

- **P (Plan/Set Goals):** Students set meaningful, personal learning goals and identify areas of struggle, which strengthens their understanding and supports learners with memory challenges.

- **L (Limit Cognitive Load):** Teachers model a single math problem, breaking it into clear, step-by-step explanations and using visuals to simplify tasks and reduce overload.
- **A (Allow Multiple Means of Expression):** Students apply their learning through writing, visuals, and self-guided inquiry, using checklists and questions to organize their thinking.
- **N (Nurture Reflection and Agency):** Students engage in self-monitoring, feedback, and reflection, building independence and deeper conceptual knowledge of fractions.

Overall, the PLAN framework equips teachers with practical tools for scaffolding fraction instruction while empowering students to take ownership of their learning.

Session 3: Lesson Implementation and Progress Monitoring

The final learning component, Session 3, serves as a tool for course designers to measure the effectiveness of the UDL MWM Design Tool, as well as serves as a mechanism for accountability among participants. The objective of the session will focus on participants committing to implementing the MWM tool, a crucial aspect of the course. The final session will take place over the spring 2027 period and revolve around participants utilizing the lesson plan tool and assessing student learning and effectiveness. Participants should identify challenges with the tool and measure student progress over time, as well as provide key effectiveness measures for product designers to assess the overall effectiveness of the tool, including re-teaching opportunities for participants to implement further in their classrooms. In addition, course designers will analyze participant feedback through the course survey to determine how math teachers best respond to in-service, thereby laying the groundwork for Year 2 development to refine instructional modules and create additional UDL-informed lesson models.

The third and final session of Year 1 will evaluate the effectiveness of the MWM Design Tool while serving as a mechanism for participant accountability. During late fall 2026 and spring 2027, Session 3 will comprise qualitative and quantitative data collection and analysis of two components of the overall MWM Design Tool implementation phases. First, participant educators will complete the participant feedback survey for designers to determine the efficacy of professional learning sessions and participant implementation with fidelity indicators for future program improvement. Second, additional qualitative and quantitative measures, built into the UDL MWM Design Tool, support participant reflections qualitatively during student observations in the classroom and measure effectiveness over the December 2026 through June 2027 time periods. These measures will inform participants as practitioners in refining their application of the tool and reviewing student quantitative performance outcomes over the spring semester grading periods. In addition, the class implementation of the tool in classroom practice involves participants assessing student progress, documenting challenges, and identifying opportunities for re-teaching. Finally, both feedback instruments, collected through surveys and effectiveness measures, will inform course designers in refining the MWM Design Tool and instructional modules, as well as determine effectiveness to increase student performance in building and retaining fractional magnitude skills to support algebraic success and inform implementation for Year 2 development of additional UDL-informed lesson models.

Session 4: Teacher Rounds and MWM Design Tool Implementation

Plan developers will engage district-level leadership in future instructional development to implement UDL principles in lesson design through instructional learning school communities in Year 2 (2027–2028). Previously discussed planning includes the following to engage district-level schools: utilization of school leadership teams to guide systematic instructional learning through Expert Alliance of Scholars (EAS) teacher round rotations. EAS teacher rounds will lead to UDL-designed, student-centered lesson plans in fraction knowledge constructed from Year 1 data and classroom observation analysis. EAS participants will engage in collaborative planning, district-level lesson plan implementation initiatives, and continued data collection through classroom observations to achieve desired methodologies for local and state-level implementation. Instructional learning opportunities should increase effective school-wide participation via learning community rotations, such as the following:

- Selection of targeted instructional strategies to review student cohort performance in Grade 8 math and algebra.
- Identification of teacher experts to teach targeted and evidence-based instructional methodologies from the initial UDL math and WM participant pool as leads.
- Lesson planning, design, and intervention integration as an inclusive education model focused on building student learner agency and building algebraic knowledge.
- Conducting of instructional observations.
- Reflection, feedback, and implementation phase—Years 3 (2028–2029) and 4 (2029–2030).

Teachers are crucial decision-makers and contributors to school improvement and help increase school-wide stakeholder engagement in supporting instructional priorities (Bolman & Deal, 2021). Within this framework, teacher leaders will collaborate with reluctant or underperforming colleagues to shift belief systems and foster their transition into shared decision-making roles within the school community, which is essential for school-wide implementation of UDL in secondary mathematics. Specifically, instructional development will emphasize UDL principles that integrate WM strategies into mathematics instruction, including the use of scaffolding, chunking of complex tasks, multiple representations of mathematical concepts, and opportunities for repeated practice with feedback. These approaches align with the UDL action and expression principle, ensuring that all learners can access, process, and demonstrate mathematical understanding. In partnership with local and district-agency leadership, product developers will continue to engage in the instructional development of secondary mathematics educators to deepen mastery of UDL principles and equip them with evidence-based strategies that support both math content acquisition and address the cognitive demands of WM to support students with SLDs and/or MD.

Administrative Support (District Leadership/Funding/Resources)

Educator resources to create additional collaboration opportunities within the master schedule will support instructional learning. For example, an increase in substitute teachers allows teachers to collaborate on lesson design and participate in teacher rounds to support shared instructional methodologies using universal lesson design. Special education teachers can serve as specialists and resources for general education teachers to support paradigm shifts in teaching methods. Additional teaming is necessary to support lesson implementation, reflection, actionable next steps, and possible teacher rounds for peer collaboration feedback. The benefits of increased substitute staffing, restructuring, and staffing resources support a reduction of isolated instruction and viable collaborative opportunities for teachers. Implications for these support systems can redefine roles and responsibilities, including redefining para-instructional aide support, with special education teachers interacting with general education colleagues, students, and parents.

Program Participant and Lesson Effectiveness Assessment Model

PD and Implementation Effectiveness

Plan developers will utilize a participant survey to evaluate the future effectiveness of the participant implementation and the effectiveness of the MWM Design Tool. The survey design will be based on the Kirkpatrick model and will function as both an assessment tool and an effectiveness measure. Participant surveys will provide feedback to guide future learning activities and necessary revisions to the lesson tool.

The Kirkpatrick model will serve as the foundation for evaluating participant beliefs and values about the training experience. The model includes four distinct levels designed to assess overall program effectiveness. According to Kirkpatrick and Kirkpatrick (2016), who further developed the original framework of the late Dr. Don Kirkpatrick, the blended evaluation model incorporates questions aligned with all four assessment levels. Participant implementation will be evaluated using the levels of the Kirkpatrick model. According to Mind Tools Content Team (2025), the Kirkpatrick model evaluates training effectiveness through four levels.

The survey will include all four levels of the model, including sample questions:

- Level 1—Reaction: measures participant satisfaction with the training.
    - Was the training meaningful and relevant?
    - Was the training engaging and did it hold your attention?
    - Was the content training useful and applicable?
- Level 2—Learning: assesses knowledge and skill acquisition.
    - Did the training increase your knowledge of UDL action and expression?
    - Did the training improve your knowledge and skill acquisition?
- Level 3—Behavior: evaluates the intent to apply learning to instructional practice.

  - Do you intend to apply UDL through math and WM strategies in your math instruction?
  - Can you identify specific opportunities in your curriculum to apply what you have learned?
- Level 4—Results: captures evidence of sustainable implementation and outcomes.
  - Can you see how these strategies improve student learning outcomes
  - Do you believe these practices can be sustainable in your instructional methodology? (Kirkpatrick & Kirkpatrick, 2016)

At Level 1, participants will indicate whether the training was meaningful. At Level 2, evaluators will determine whether participants gained new knowledge and skills. At Level 3, the evaluation will focus on participants' intent to implement new practices. At Level 4, evidence serves to determine whether participants effectively apply their learning in instructional settings. This framework, referred to as the New World Kirkpatrick model, will be used to structure the survey (Kirkpatrick & Kirkpatrick, 2016). Two to three open-ended questions will capture reflective feedback from participants regarding the training experience. Collectively, these levels will provide a comprehensive measure of both participant progress and program effectiveness (Mind Tools Content Team, 2025). Lesson plan design and implementation trend data collected using this model will support (a) implementation with fidelity and (b) frequency monitoring from passive learning to active engagement within the instructional learning process.

Participant PD and Implementation Evaluation

The evaluation design will incorporate a Likert-type rating scale to assess engagement across the four Kirkpatrick levels. For example, Level 4 will examine the extent to which participants apply their learning in the classroom. The survey will include items rated on a 5-point scale: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). Participants will respond to items addressing enjoyment of the course, knowledge gained, and the use of instructional methodologies with fidelity. Two additional items will ask participants to reflect on how the course contributed to their teaching methodologies. Before and after the course, participants will also rate their level of effort and contribution to learning using the following categories: poor, fair, satisfactory, very good, and excellent.

Math and WM Design Tool Assessment Models

Qualitative participant self-reflection and perception surveys will capture how practitioners experienced the lesson template. Self-reflections will include ease of implementation, observed student engagement or disengagement, and any challenges encountered. Reflection prompts directly connect to WM and UDL action and expression, enabling teachers to conceptualize intervention strategies in relation to their classroom realities. This model emphasizes the practitioner’s voice and gauges both confidence and feasibility in sustaining the intensive intervention.

A student learning and engagement outcomes model will assess lesson tool effectiveness and its’ impact on student learning and engagement. Participants’ use of curriculum-based formative assessments, such as exit tickets, quick writes, or number line placement tasks, as measures of student learning and fractional skill acquisition learning reveals whether scaffolds are improving understanding. Student engagement monitoring through teacher observations and coaching interactions will inform the efficacy of the tool. Recorded student interactions from teacher observations are measured using pre- and post-assessments to evaluate student performance. Measures include student utilization of support, recording and expressing their learning in various ways, and reflections on their learning process annotated in their lesson notes.

This model ensures that the evaluation extends beyond teacher implementation to capture the direct influence of UDL in math and WM supports on student learning experiences. Teachers will report back on the findings as part of the Session 3 progress monitoring evaluation, explicitly using the UDL Action & Expression Fidelity of Implementation Rubric to assess the lesson tool and implementation efficacy. Student learning and engagement outcomes will measure effectiveness of the template by impact on student performance. Participants' use of curriculum-based formative assessments, such as exit tickets, quick writes, or number line placement tasks, as measures of student learning and fractional skill acquisition learning reveal whether scaffolds are improving comprehension. In addition, student engagement monitoring through teacher observations and coaching interactions will inform the efficacy of the tool. Recorded student interactions from teacher observations, measured using pre- and post-assessments, evaluate student performance. Measures include student utilization of support, recording and expressing their learning in various ways, and reflections on their learning process annotated in their lesson notes.

Comprehensive Participant and Lesson Template Assessment Review

School-level teacher instructional leadership teams will review program participant survey results and comprehensive student performance data to inform future instructional learning and lesson template design next steps. This information will inform leadership of the instructional learning course's effectiveness and will guide future recommendations for student-centered instructional practices. In addition, school-level administration will submit findings and after-action reports to regional and district leadership for plan review and modification for district-level instructional learning planning and lesson template implementation district-wide. Upon completion of the instructional learning cycle, plan developers will analyze the pre- and post-assessment instruments, directly connecting to high-quality instruction through high student engagement and expectations. Demographics collected by population will serve to demonstrate representation across the district. Activities strategically targeting teacher growth mindset will be highlighted in the final analysis as an indicator of success or to identify areas for improvement in future instructional development courses.

SECTION 4: SUMMARY OF RESULTS

Synthesis of the Problem

Product designers identified the problem of analyzing nationwide NAEP student performance data in eighth-grade math over the last 20 years. A narrow focus examined the performance of students with and without disabilities in mathematics, including eighth-grade mathematics. NAEP statistical performance data led to an investigation into the factors that contribute to success in algebra. Given that secondary education is the most widely known entry point for learning algebraic concepts, the systematic literature review focused on secondary math education, including middle and high school-aged students with SLDs, such as those with MD (not necessarily formally identified). Empirically reviewed studies sought to answer the fundamental skills necessary for algebraic success and the respective challenges of students with SLDs in secondary mathematics. Based on these determinants, the study's focus sought to establish the functional relationship between universally designed guidelines, action, and expression in relation to activating WM to attend to math instruction, with findings conceptually focused on fractional knowledge as a pathway to algebraic learning.

Empirical studies sought included qualitative, quantitative, single-subject, and mixed-methods studies. All studies reviewed initially sought solutions to the underperformance of students in algebra and identified the necessary skill sets that supported algebraic success. Booth et al. (2014) identified fractions as indicators of NU versus U fraction magnitude that activate WM, a mechanism that supports students with SLDs and is a pivotal factor in responding to the questions sought and the course of the study. Through Booth et al.'s work and subsequent studies, it became evident that product development could strengthen students' understanding of fractions, which in turn enhances their NU proportional number sense—a skill necessary for success in algebra and subsequent math disciplines (Booth et al., 2012).

An excerpt from DeWolf et al. (2015) addressed aspects of the review questions. Their study's findings were significant for the final product design because they identified the key skills necessary to support students in developing algebraic skills for success in algebra. Importantly, their study revealed that these skills are prerequisites for success in higher-level math courses and, consequently, in postsecondary pursuits. The literature research uncovered several skills hypothesized to be crucial for success in algebra, including ratios and proportions, fractions, and word problem-solving. Building on these findings, a focus on fractions was decided. Early findings included the duality of fractions, in conjunction with mathematical relationships, which represent the magnitude of both the numerator and denominator, or the division of *a* by *b,* which is similar to the duality of algebraic expressions. Furthermore, they found that students must understand they can use algebraic expressions to represent both the relationships between quantities and the processes used to find an unknown quantity derived from them (DeWolf et al., 2015).

Further, Fuchs et al. (2014), addressed review questions with a focus on WM as a key determinant in how students respond to specific instructional approaches in fractions. Their research revealed that WM supports students' ability to interpret and manipulate fraction magnitudes, particularly for those with LDs in mathematics. Regarding connection to UDL through action and expression and notable for the final product, the study revealed a significant contrast in the effectiveness of instructional approaches: students with lower WM benefited more from conceptual instruction—which emphasizes understanding the *why* behind mathematical concepts—than from procedural instruction, which focuses on teaching the *how* through step-by-step methods (Fuchs et al., 2014).

Expected Impact of Improvement Initiatives

The PoP, which involves students with SLDs currently underperforming in mathematics Grade 8 nationwide, has been identified by investigators. The goal is to remedy the disparity between specific learning-disabled and non-learning-disabled students in secondary mathematics, specifically algebra. Reviewed empirical research laid the groundwork in identifying several precursors for increasing the probability of success in algebra, ratios, proportions, word problems, and fractions. Given the trend of student challenges in gaining fractional knowledge and the breadth of research within the scope of middle and high school level mathematics research in the subject area of fractions and its relation to algebra, fractional knowledge and magnitude interchangeably were researched to determine components of fractional magnitude that served to support building algebraic skills for students with SLDs.

Research led to findings in fraction magnitude as well as activation of WM using mechanisms to reduce cognitive load in students with SLDs. By making connections between UDL principles through action and expression, compiled research served as building blocks for designing a lesson template based on UDL action and expression for implementation in middle and high school mathematics classrooms. Based on the study's goal, the literature review conducted informed product design of an instructional tool that supports increased knowledge acquisition of fraction concepts, thereby building the skillsets necessary for algebraic success. This study hypothesized that the implementation of the MWM Design Tool in local-agency school systems would enhance the performance of students with SLDs in secondary mathematics and reduce the math achievement gap between students with SLDs and their nondisabled peers.

Empirical research noted the significance of SLD students' success rates in secondary math as indicators of success in higher-level mathematics as well as postsecondary collegiate and career pursuits. Indeed, success in higher-level mathematics was often a determinant of employability in the work force and sustainable collegiate attendance and graduation, thus signifying great impact on SLD students' ability to remain competitive in a global workforce.

In addition to increasing SLD students' performance in algebra, shifts in teacher mindset toward inclusive education practices serve to increase knowledge and skills necessary to address the students with diverse needs and build student learner agency within the general education classroom. Secondary math educators will utilize the instructional tool in their classroom routinely to support knowledge acquisition through UDL's action and expression principle by activating executive functioning in students with SLDs and/or MD in order to attend to instructional tasks and decrease cognitive load to activate WM further. Participants will engage in the *why* of UDL to make connections to the significance of strengthening WM and to conceptual understanding of magnitude knowledge. Expected outcomes should encourage a shift in teacher mindset from teacher-centered to student-centered learning, foster teacher efficacy, and increase student performance outcomes in algebra to support success in higher-level secondary math, thereby narrowing the math achievement gap between students with SLDs and their nondisabled counterparts.

Analysis of Next Steps

The next phase of this work emphasizes sustained progress monitoring and continued collaboration through the EAS. By engaging district-level leadership and school instructional learning communities, Year 2 efforts will focus on embedding UDL principles into lesson planning and instructional practice. School-level instructional leadership teams comprised of math educators and administrators will initiate the EAS teacher-round rotations wherein expert teachers model student-centered, UDL-based math lessons. These rotations will create opportunities for collaborative planning, implementation, classroom observation, and reflection, ensuring that instructional strategies are both evidence-based and inclusive. This process strengthens teacher leadership, expands stakeholder engagement, and supports a shared vision of instructional improvement (Bolman & Deal, 2021).

School-wide learning communities will continue to elect targeted instructional strategies utilizing universal design constructs through continuous instructional improvement and guided professional learning resulting from initial participant survey and classroom observation data collected. Identification of participants from the initial pilot program and implementation of the observation cycle will involve informing modified interventions and engaging in reflective feedback cycles to improve the lesson tool. Central to this work is the development of teacher leaders who can collaborate with reluctant or struggling colleagues, shift belief systems, and advance school-wide implementation of UDL frameworks.

At the district level, researchers will remain engaged in supporting secondary educators' mastery of UDL principles. They will foster shared leadership and continuous instructional growth to increase students with SLDs' academic and performance outcomes and reduce the performance gap between students with SLDs and their nondisabled peers in mathematics, specifically algebra, as evidenced by NAEP annual and long-term statistical data, over years 2026–2030. According to NCES (2025), the NAEP Data Explorer provides national, state, and district results as well as student groups for performance measures and comprehensive analysis. The Nation's Report Card (2024) serves as a statistical resource for monitoring student performance. It provides access to data that can be generated and analyzed by product developers, as well as by state and local education leaders, to track assessment trends for students with SLDs. These trends are often examined through Grade 8 comparisons across four-year intervals. Users can access this information through the Explore Assessment Data tool, under the Resources and Data Tools subcategory, which generates secondary student performance reports via the NAEP Data Explorer. The NAEP Data Explorer tool will create customizable tables, graphics, and reports, specified by the reviewer, which, for purposes of the study, will include students with SLDs on IEPs, excluding reasonable accommodated students (NCES, 2025). Final analyses will include a gap analysis comparing the performance of students with and without disabilities, examining performance disparity gaps, and tracking trends in narrowing performance margins between the two groups of students under review.

Limitations of the Research and Future Recommendations

Empirical researchers have noted persistent challenges in testing UDL as an instructional intervention because of its adaptable nature. A limitation is the absence of an agreed-upon operationalization of UDL across empirical studies that restricts researchers' ability to meet evidence-based criteria for sought-after testing. As a result, despite numerous empirical and descriptive studies, researchers still face barriers to designing interventions tested for evidence-based effectiveness.

Historic studies have attributed positive outcomes—such as improved attitudes, beliefs, and self-efficacy—to practices aligned with UDL principles. However, these results are not conclusive evidence of UDL's direct effectiveness, thus dictating the need for more precise operational definitions of UDL so that both researchers and practitioners can access transparent information about intervention design and learner outcomes. In addition, gaps remain in research examining the mechanisms of executive functioning—particularly working memory and central executive processes—and their relationships to secondary mathematics—specifically fraction magnitude—which support the development of algebraic skill sets. While connections between executive functioning, mathematics, and students with SLDs appear linear, research has yet to align methods to measure these relationships over time.

To test the functional relationship between the implementation of UDL guidelines and student-identified achievement in mathematics, recommendations for future research include a single-case alternating-treatment design based on clearly defined dependent and independent behaviors identified from historical student performance data. A single-subject study will allow for an operationally defined study with clearly defined dependent and independent variables, including the tested intervention, to examine and measure the implementation of UDL principles in instruction for subsequent empirical investigations. In addition, future research on the cross-curricular implementation of the MWM tool need not be limited to secondary math; research in elementary math is encouraged. Moreover, other content-specific areas can be explored procedurally, such as social studies and English language arts. Finally, recommendations for researchers, in recognition of the social-emotional overlay, should consider math learning and UDL guideline engagement wherein guideline engagement and learner agency can support social-emotional learning and address potential math phobias associated with math achievement among students with specific learning disabilities.

SECTION 5: PRODUCT FOR PRACTITIONERS—MATH AND WORKING MEMORY DESIGN TOOL

The MWM Design Tool implementation follows a structured instructional framework that begins with professional learning, extends through the PLAN lesson design model, and continues into long-term assessment, monitoring, and collaborative practice. Following is an overview of its application:

- MWM Framework Overview:
    - Professional Learning Course (15 hours, university credit optional): Focused on the UDL action and expression principle (Considerations 6.1–6.3), which is designed to shift teacher beliefs toward inclusive math instruction for students with SLDs.
    - Professional Learning Pathway:
        1. Online pre-work.
        2. Face-to-face collaboration on PLAN framework.
        3. Implementation and progress monitoring.
    - Ongoing Expansion: Year 1 progress monitoring; Year 2 teacher rounds and deeper integration.
- Course Implementation:
    - Target audience: Secondary/middle-grade math teachers, particularly those teaching pre-algebra and fractions.
    - Coursework (fall 2026 start): In-person modules plus lesson template applications.

    - Emphasis: Fractions as a foundation for algebra readiness, activating WM, reducing cognitive load, and promoting learner agency.
- Administrative and State Support: Program implementation involves obtaining pre-approval from the state and local education agencies and ensuring alignment with school system improvement plans, course outcomes, and university credit requirements, thereby affording participants options for teacher certification credit.
- Professional Learning Activities and Timeline:
    - Year 1 (2026–27): Online pre-work, face-to-face training, and progress monitoring.
    - Year 2 (2027–28): Teacher rounds, classroom observations, and ongoing UDL-based lesson refinements.
- Evaluation and Effectiveness:
    - Assessment Models: Kirkpatrick model (Levels 1–4: reaction, learning, behavior, results), participant surveys, fidelity rubrics, and student performance data.
    - Student Outcomes: Measured through formative assessments (exit tickets, quick writes, number line tasks), engagement observations, and pre/post data.
    - Teacher Outcomes: Growth in UDL knowledge, mindset, and collaboration capacity.
- Long-Term Goal: Participants will engage in the *why* of UDL to make connections to the significance of strengthening WM and conceptual understanding of magnitude knowledge. Although fractions will serve as the basis for the math applied, the MWM Design Tool adds flexibility to student-centered instruction through the UDL action

and expression principle, specifically Considerations 6.1–6.3, by applying scaffolded questioning to various secondary math disciplines.

APPENDIX A: CAST UDL GUIDELINES 3.0

CAST Universal Design for Learning Guidelines

The goal of UDL is **learner agency** that is purposeful & reflective, resourceful & authentic, strategic & action-oriented.

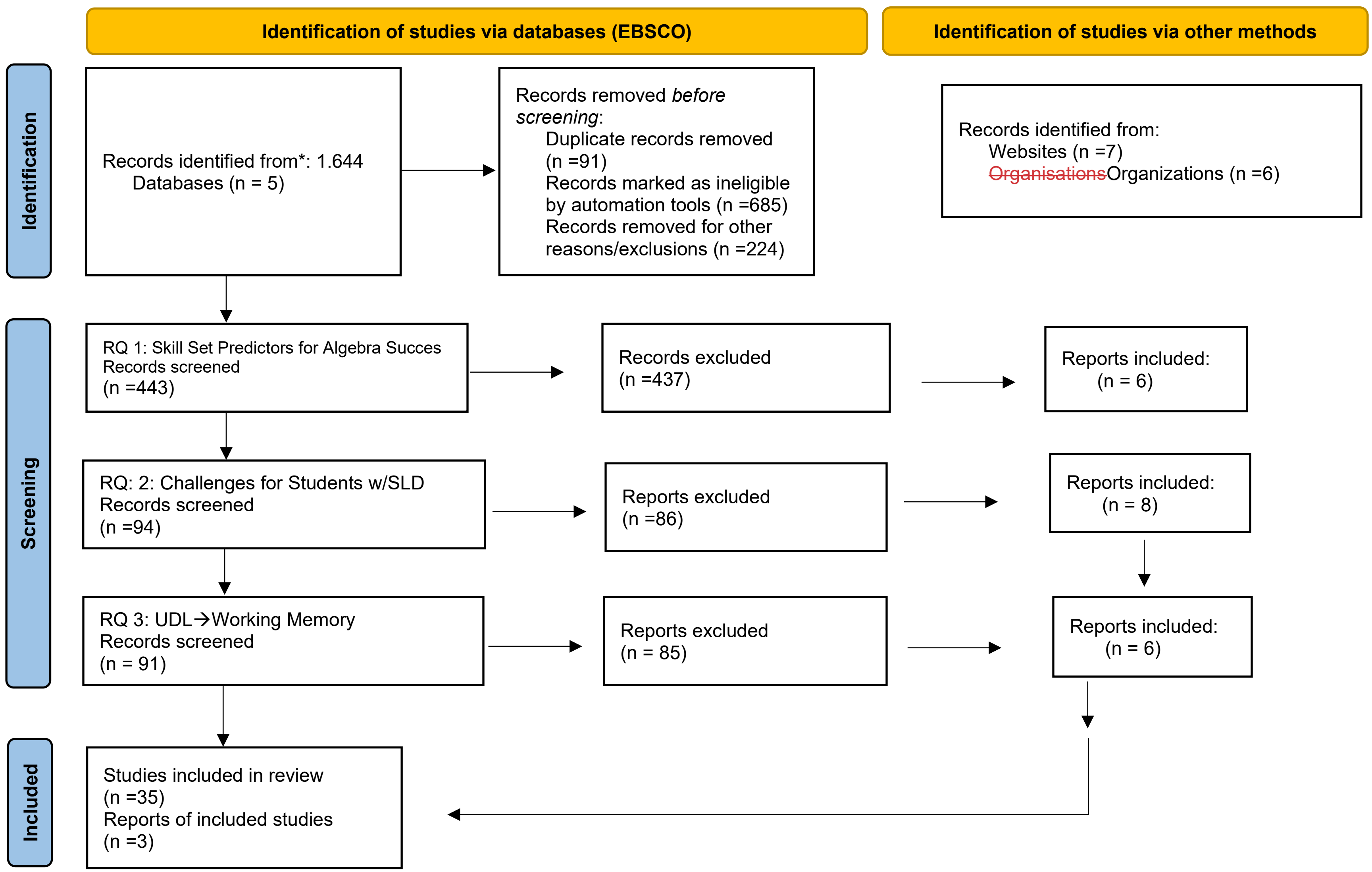
	Design Multiple Means of **Engagement**	Design Multiple Means of **Representation**	Design Multiple Means of **Action & Expression**
Access	Design Options for **Welcoming Interests & Identities** (7) • Optimize choice and autonomy (7.1) • Optimize relevance, value, and authenticity (7.2) • Nurture joy and play (7.3) • Address biases, threats, and distractions (7.4)	Design Options for **Perception** (1) • Support opportunities to customize the display of information (1.1) • Support multiple ways to perceive information (1.2) • Represent a diversity of perspectives and identities in authentic ways (1.3)	Design Options for **Interaction** (4) • Vary and honor the methods for response, navigation, and movement (4.1) • Optimize access to accessible materials and assistive and accessible technologies and tools (4.2)
Support	Design Options for **Sustaining Effort & Persistence** (8) • Clarify the meaning and purpose of goals (8.1) • Optimize challenge and support (8.2) • Foster collaboration, interdependence, and collective learning (8.3) • Foster belonging and community (8.4) • Offer action-oriented feedback (8.5)	Design Options for **Language & Symbols** (2) • Clarify vocabulary, symbols, and language structures (2.1) • Support decoding of text, mathematical notation, and symbols (2.2) • Cultivate understanding and respect across languages and dialects (2.3) • Address biases in the use of language and symbols (2.4) • Illustrate through multiple media (2.5)	Design Options for **Expression & Communication** (5) • Use multiple media for communication (5.1) • Use multiple tools for construction, composition, and creativity (5.2) • Build fluencies with graduated support for practice and performance (5.3) • Address biases related to modes of expression and communication (5.4)
Executive Function	Design Options for **Emotional Capacity** (9) • Recognize expectations, beliefs, and motivations (9.1) • Develop awareness of self and others (9.2) • Promote individual and collective reflection (9.3) • Cultivate empathy and restorative practices (9.4)	Design Options for **Building Knowledge** (3) • Connect prior knowledge to new learning (3.1) • Highlight and explore patterns, critical features, big ideas, and relationships (3.2) • Cultivate multiple ways of knowing and making meaning (3.3) • Maximize transfer and generalization (3.4)	Design Options for **Strategy Development** (6) • Set meaningful goals (6.1) • Anticipate and plan for challenges (6.2) • Organize information and resources (6.3) • Enhance capacity for monitoring progress (6.4) • Challenge exclusionary practices (6.5)

CAST | Until learning has no limits®

Suggested Citation: CAST (2024). Universal Design for Learning Guidelines version 3.0 [graphic organizer]. Lynnfield, MA: Author.

From "CAST (2024). Universal Design for Learning Guidelines version 3.0 (graphic organizer). Lynnfield, MA: Author.

APPENDIX B: PRISMA 2020 FLOW DIAGRAM FOR NEW SYSTEMIC REVIEWS



Note. Adapted from *The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews* by Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Moher, D. (2021), *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71. This work is licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

APPENDIX C: CONTENT MATRIX

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
Almeqdad, Q. I., Alodat, A. M., Alquraan, M. F., Mohaidat, M. A., & Al-Makhzoomy, A. K. (2023). The effectiveness of universal design for learning: A systematic review of the literature and meta-analysis. *Cogent Education*, *10*(1), 2218191. https://doi.org/10.1080/2331186x.2023.2218191	Authors examined the effectiveness of UDL principles in educational settings.	Effectiveness of UDL principles in instruction.	Application of UDL principles using structured PD or classroom interven-tions to implement; linked to higher learning gains and future planning and practice.	What are research trends in UDL studies (2015–2021, English/Arabic)? What effect sizes emerge by UDL principles, participants, curriculum, intervention level, and design?”	Systematic review found studies across six countries, K–12 and higher ed, applying UDL via PD or interven-tions, mostly using one-group quantitative designs.	Meta-analysis found large overall effect (g = 3.56) with high heterogenei-ty; significant effects for single-group, student, domain-specific, and quantitative studies.	N/A	N/A	Most studies (9 of 13) were US-based, reflecting its diverse, inclusive education model supporting UDL. UDL was effective across teachers and students, with strongest benefits for diverse K–12 learners.	N/A
Booth, J. L., & Newton, K. J. (2012). Fractions: Could they really be the gatekeeper’s doorman? *Contemporary Educational Psychology, 37*(4), 247–253. https://doi.org/10.1016/j.cedpsych.2012.07.001	Study examined the relationships between middle school students’ fraction and whole number magnitude knowledge and their readiness for algebra.	Specifically investigated how magnitude knowledge relates to measures of algebra readiness and explored the significance of fraction knowledge.	Knowledge of fraction magnitudes is a better representa-tion of deep number knowledge than whole number magnitude knowledge.	Examined whether fraction and whole number magnitude knowledge independent-ly or generally predict algebra readiness.	Quantitative	32 (18 female/14 male) ages 12–14 years of age; all middle school students.	IV includes the knowledge of fraction and whole number magnitudes measured by tasks like number line estimation.	Researchers measured algebraic readiness testing students on dependent variable (DV) as measures of algebra readiness: feature knowledge, equation solving and word problem solving.	Study suggests that knowledge of fraction magnitudes rather than whole number magnitudes influence students’ skill in early algebra	Outside criteria (2012 study)
Booth, J. L., Newton, K. J., & Twiss-Garrity, L. K. (2014). The impact of fraction magnitude knowledge on algebra performance and learning. *Journal of Experimental Child Psychology*, *118*, 110–118. https://doi.org/10.1	Author sought to replicate and extend previous findings from 2012 on the relationship between fraction and whole number magnitude knowledge skills for	Identification of predictor skills necessary for success in algebra.	Fraction magnitude understand-ing supports algebra learning, with numerator–denominator relationships key to grasping equivalents	Examined how fraction and whole number magnitude knowledge (U vs. NU) predict Algebra 1 performance and learning.	Quantitative	72 8th-grade students (37 female, 34 male, 1 unspecified) across five classrooms; all students enrolled in non-honors Algebra I course using Cognitive Tutor	Cognitive Tutor with pre-/post-test to assess learning; no control group assigned.	No control group	Fraction magnitude knowledge predicts algebra improvement, supporting NMAP (2008) view of fractions as foundational for algebra.	1.0

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
016/j.jecp.2013.09.001	students taking algebra.		and proportions.			software.				
Ching, B. H.-H., & Li, X. Y. (2024). Early fraction relational reasoning uniquely predicts later algebraic thinking in children: A longitudinal study. *Contemporary Educational Psychology*, *79*, 102300. https://doi.org/10.1016/j.cedpsych.2024.102300	Study examined longitudinal links between fraction relational reasoning, cognitive factors, and 6th-grade algebra performance.	Further identifies skills supported by research as predictors of algebra acuity; longitudinal study of 4th-graders tested 18 months apart for algebra predictors.	Fraction relational reasoning, magnitude, and arithmetic uniquely predict algebra perform-ance more strongly than domain-general or decimal knowledge.	Examined if fraction relational reasoning uniquely predicts algebra and whether fraction knowledge outperforms domain-general and decimal knowledge as predictors.	Quantitative study using longitudinal and relative weight analysis to measure perform-ance of participants from fourth grade to sixth grade on algebraic tasks.	Randomly selected schools/386 students (182 males, 204 females), all normal intelligence.	IVs: fraction relational reasoning, fraction magnitude, fraction arithmetic, decimal magnitude, attentive behavior, counting recall, listening recall.	Algebraic performance.	The results were conclusive. Fraction relational reasoning was a significant, stronger predictor of algebra performance than other cognitive factors, including decimal knowledge.	1 (.97)
Cowan, N., Bao, C., Bishop-Chrzanowski, B. M., Costa, A. N., Greene, N. R., Guitard, D., Li, C., Musich, M. L., & Ünal, Z. E. (2024). The relation between attention and memory. *Annual Review of Psychology*, *75*, 183–214. https://doi.org/10.1146/annurev-psych-040723-012736	Study examined practical consequences of attention–memory links across methodologies, including WM, LTM, individual differences, development, brain function, and neuropsycho-logical conditions.	Mechanisms of embedded processes. The embedded processes theoretical view emphasizes the attention–memory relation.	Higher WM capacity in attention-demanding tasks is associated with better general fluid intelligence, arithmetic perform-ance, and algebraic perform-ance.	Synthesis of varied methodol-ogies–state of the field.	Quantitative Review	N/A	N/A	N/A	Authors show how computational models explain cognitive load effects (e.g., recall decline with distraction), representing time and task demands without fixed measures.	N/A
DeWolf, M., Bassok, M., & Holyoak, K. J. (2015). From rational numbers to algebra: Separable contributions of decimal magnitude and relational understanding of fractions. *Journal*	Identified which earlier math skills, especially fractions and decimals, predict algebra success or failure.	Algebra underper-formance.	Study examined how fraction relational understand-ing and decimal magnitude support early algebra success.	Examined rational number knowledge as predictor of early algebra, comparing fraction magnitude, relational	Quantitative	7th-grade pre-algebra students from two suburban LA schools (5 classes, varied skill levels, end of year).	IVs: numerical understanding —fraction, decimal, whole number line estimation; relational fraction knowledge.	Algebra performance	Specific measures identified as key predictors of math performance: (1) division via numerator–denominator relation, (2) magnitude	1.0

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
of Experimental Child Psychology, *133*, 72–84. https://doi.org/10.1016/j.jecp.2015.01.013				understand-ing, and decimal tasks.					approximation on number line.	
DeWolf, M., Bassok, M., & Holyoak, K. J. (2016). A set for relational reasoning: Facilitation of algebraic modeling by a fraction task. *Journal of Experimental Child Psychology*, *152*, 351–366. https://doi.org/10.1016/j.jecp.2016.06.016	Study tested if relational fraction thinking helps middle school and college students construct correct algebraic equations for multiplicative comparisons.	Relational fraction reasoning fosters a relational set, promoting algebraic modeling that promotes student's tendency to model relations using algebraic expressions.	Relational fraction understand-ing uniquely predicted algebra performance beyond procedures, fostering relational reasoning for algebraic modeling.	Tested if fraction relational reasoning boosts algebra equation construction (esp. division) and transfers across ages and to word problems.	Quantitative	7th graders vs. college students.	IVs: age group (7th vs. college), initial task (fraction relations vs. procedures), and equation format (division vs. multiplication).	Fraction Algebra Procedures Control Task The DVs are the performance on the word problem-solving task and the algebra equation construction task, analyzed separately.	Fraction relations tasks improved algebra equation construction for 7th graders and college students, with strongest effects for 7th graders on division equations in the target algebraic modeling task.	1.0
Fuchs, L. S., Schumacher, R. F., Sterba, S. K., Long, J., Namkung, J., Malone, A., Hamlett, C. L., Jordan, N. C., Gersten, R., Siegler, R. S., & Changas, P. (2014). Does working memory moderate the effects of fraction intervention? An aptitude–treatment interaction. *Journal of Educational Psychology, 106*(2), 499–514. https://doi.org/10.1037/a0034341	Study tested whether building automaticity in fraction measurement interpretation supports at-risk students by reducing cognitive load.	Aptitude in development of an individual-ized intervention to develop automaticity in students with SLDs in math.	Students' ability to consolidate meaning and the possible attentive components connected to the central executive system and WM.	Whether the effects of fluency versus conceptual conditions (aptitude treatment interactions) differed as a function of students' WM.	Quantitative	4th-grade at-risk students (n = 243).	Two conditions: fluency (speeded practice on measurement topics) and conceptual (reasoning with manipulatives on same topics).	Business as usual–Envision Math	Aptitude-treatment interaction: weak WM students benefited from conceptual activities, stronger WM from fluency; both outperformed control, mediated by fraction interpretation.	1.0
Gravel, J. W. (2018). Going deep: Leveraging	How does the UDL framework	UDL and functional relationship	Teachers must shift from access	How, if at all, do teachers	Qualitative case study; 10-week	2 fifth grade co-teachers and their	N/A	N/A	Co-teachers applied UDL guidelines—	Met

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
universal design for learning to engage all learners in rich disciplinary thinking in ELA. *Teachers College Record: The Voice of Scholarship in Education*, *120*(3), 1–40. https://doi.org/10.1177/016146811812000302	prompt disciplinary thinking?	between content to facilitate student learning.	to learning; UDL supports all students' engagement in disciplinary thinking.	working within a school that explicitly promotes the UDL framework use UDL to prompt students' disciplinary thinking in ELA?	ELA session; data gathered: videotaped obser-vations, instruction-al material collection, interviews, co-teachers, collection of student work.	class of 21 students with and without documented disabilities.			both prescribed and adapted—to create opportunities for all students' disciplinary thinking	
Jitendra, A. K., Dupuis, D. N., Star, J. R., & Rodriguez, M. C. (2016). The effects of schema-based instruction on the proportional thinking of students with mathematics difficulties with and without reading difficulties. *Journal of Learning Disabilities, 49*(4), 354–367. https://doi.org/10.1177/0022219414554228	Examined schema-based instruction (SBI) effects on proportional problem-solving in 7th graders with MD vs. students with math and reading difficulties (MDRD).	Studied strategy instruction on ratios/propor-tions to reduce math disparities in secondary students with disabilities, supporting proportions as predictors of algebra success.	Tested SBI to improve proportional reasoning, evaluating effective-ness by level of math difficulty.	What are the immediate, retention, and transfer effects of SBI on 7th graders with MD vs. MDRD compared to control?	Quantitative study of 260 7th graders (MD/ MDRD) testing 6-week SBI on proportional problem solving.	7th graders from prior study; RCT with pre-, post-, and retention tests; 15 teachers, 6 schools, 3 districts; SBI vs. control.	SBI intervention taught explicit problem modeling with schematic diagrams to highlight underlying mathematical relations.	"Business as Usual" math instruction.	SBI was most effective on percent problems; MD students outperformed MDRD in proportional problem solving.	1.0
Jordan, N. C., Resnick, I., Rodrigues, J., Hansen, N., & Dyson, N. (2016). Delaware longitudinal study of fraction learning: Implications for helping children with mathematics	Focus on intervention effect and measures used to assess fraction knowledge. Noted WM association with mathematics disabilities.	Study found cognitive, math, and non-math factors predict fraction learning; attentive behavior uniquely predicted	Longitudinal research supports number line instruction for students with math disabilities or difficulties.	The study examined growth in fraction knowledge over time and the impact of specific interven-tions.	Quantitative longitudinal study of fraction develop-ment in Grades 3–6.	>500 3rd graders, diverse in gender, ethnicity, socioeco-nomic status (60% low income), LD; focus on students with	IVs (predictors): attentive behavior, WM, verbal ability, nonverbal ability, whole number line estimation, proportional reasoning, whole number	DV (fraction outcomes): fraction number line estimation, fraction concepts, and fraction arithmetic procedures.	Children with MD struggle with whole-number and fraction magnitudes; interventions target numerical magnitude understanding to support	1 (.71) Implemen-tation of fidelity or overall attrition not explicitly stated.

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
difficulties. *Journal of Learning Disabilities*, *50*(6), 621–630. https://doi.org/10.1177/0022219416662033		fraction knowledge and achievement in LD/MD students.				or at risk for MD	calculation, and long division.		fraction learning.	
Lambert, R., Imm, K., Schuck, R., Choi, S., & McNiff, A. (2021). "UDL is the what, design thinking is the how": Designing for differentiation in mathematics. *Mathematics Teacher Education and Development*, *23.3*, 54–77.	Studied integrating UDL with design thinking to build inclusive math classrooms, emphasizing empathy and designing for marginalized learners.	Merging UDL principles with design thinking in math can create more accessible curricula, routines, tools, and spaces.	Merge UDL with design thinking to design accessible math instruction.	How do participants conceptualize (1) UDL, (2) design thinking, and (3) the intersection between the two?	Qualitative design research study of a 6-week course using qualitative data and a case study of one team; pre/post survey.	N = 45; gender, race, nondisabled and disabled; general and special education classrooms; school administration.	N/A	N/A	Results suggest PD helps teachers apply UDL, design from the margins, and view themselves as designers.	Met
Moleko, M. M., & Mosimege, M. D. (2021). Flexible teaching of mathematics word problems through multiple means of representation. *Pythagoras (10122346)*, *42*(1), 1–10. https://doi-org.proxy-um.researchport.umd.edu/10.4102/pythagoras.v42i1.575	This study considers some aspects of the UDL framework, specifically multiple means of representation, to analyze and promote flexible teaching through inclusive practices.	Study of teachers applying UDL in instruction/ assessment, focusing on multiple means of representation for flexible math teaching and secondary lesson design.	UDL promotes flexible, inclusive teaching; MMR supports math instruction by offering varied language, symbols, and perceptual entry points for diverse learners.	How can the multiple means of representation be implemented to guide flexible teaching of mathematics word problems?	Exploratory descriptive design. Qualitative study. MMR operationally defined.	Sample-purposive sampling-informant selection; deliberate choice due to the qualities possessed by the individual.	N/A	N/A	Study shows UDL's MMR aids math instruction/ assessment through precise language, expressions, and symbols, fostering knowledgeable, resourceful learners.	1.0
Myers, J. A., Brownell, M. T., Griffin, C. C., Hughes, E. M., Witzel, B. S., Gage, N. A., Peyton, D., Acosta, K., & Wang, J.	Meta-analysis of math interventions for Grades 6–12 students with MD, examining design features	Assessed impact of intervention type and study design features on math intervention	Proposed meta-analysis of secondary math interventions for MD,	Meta-analysis	Variance estimation and meta-regression estimate each predict effect while controlling	MD defined as (1) students with math LD (e.g., dyscalculia, WM/reasoning	IVs (moderators): intervention length, model (CBI, TBI, VR, SBI, other), content domain, group size,	Mathematics achievement effect sizes (heterogeneity) derived from outcome measures (standardized or researcher-developed math	Interventions support secondary students with MD across domains; efficacy varied by content and	1.0

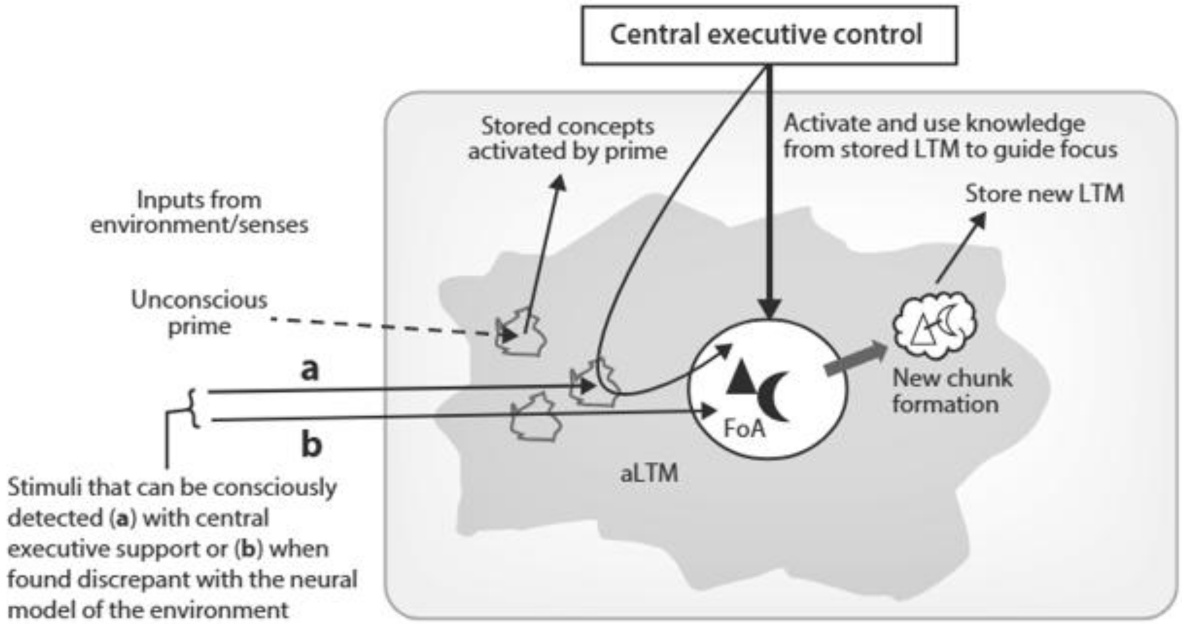
Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
(2021). Mathematics interventions for adolescents with mathematics difficulties: A meta-analysis. *Learning Disabilities Research & Practice (Wiley-Blackwell)*, *36*(2), 145–166. https://doi-org.proxy-um.researchport.umd.edu/10.1111/ldrp.12244	influencing efficacy to bridge research-to-practice gap.	outcomes.	identifying effective models and domain impacts.		for other moderators' confound-ing effect and identify moderators of intervention effective-ness.	challenges) and (2) low-performing, at-risk students without formal LD.	setting, measure type, fidelity, interventionist, publication type, study quality, author bias.	tests) across 139 outcomes.	length. Fractions had smaller effects than multi-domain studies. CBI, TBI, and VR all showed significant effects, with CBI strongest.	
Powell, S. R., Gilbert, J. K., & Fuchs, L. S. (2019). Variables influencing algebra performance: Understanding rational numbers is essential. *Learning and Individual Differences*, *74*, 101758. https://doi.org/10.1016/j.lindif.2019.101758	Examined variables influencing algebra success in high-performing college students to identify key predictors of competence.	Explored math (rational number knowledge, fact fluency, anxiety) and literacy (reading, spelling) factors influencing algebra performance.	Tested SBI effects on proportional problem solving in students with MD and students with MDRD.	How do rational number skills, fact fluency, math anxiety, reading, and spelling influence algebra perform-ance?	Quantitative Study—use of dominance analysis to assess the relative importance of different interven-tions in predicting algebra perform-ance.	362 college volunteers (2014–2016), diverse demo-graphics; avg. age 20.5.	Examined influences on algebra performance: rational number skills, fact fluency, math anxiety, reading, and spelling.	Algebra performance.	Among 5 variables, rational number performance was strongest, explaining 33% of variance in algebra performance.	1.0
Rojo, M., King, S., Gersib, J., & Bryant, D. P. (2023). Rational number interventions for students with mathematics difficulties: A meta-analysis. *Remedial and Special Education*, *44*(3), 225–238. https://doi.org/10.1177/074193252211	Systematic review/meta-analysis of rational number interventions examined instructional foci, effect size, and moderators; most targeted fraction magnitude and arithmetic.	Examined impact of rational number understand-ing interventions on math outcomes for students with MD, including those with LDs.	Meta-analysis of rational number interven-tions for students with MD; evaluates notations, concepts, and intervention features affecting	RQ1: What notations/ concepts are taught in rational number interventions for students with MD? RQ2: How do these interventions and their features affect math	Systematic review and meta-analysis of studies on fraction magnitude and arithmetic instruction.	Most participants (>50%) had MD or disaggregated MD data; excluded studies with unmatched treatment/control populations.	The IV was a mathematics intervention with a focus on teaching any of the rational number notations (i.e., fraction, decimal, and/or percentage).	The DV was a measure of students' mathematics performance.	Rational number interventions showed strong effects (g = 1.02) over control; larger for proximal measures. Limitations: many fraction-focused studies, high heterogeneity.	1.0 (great use of PRISM diagram as an example)

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
05520			outcomes.	outcomes?						
Root, J. R., Cox, S. K., Saunders, A., & Gilley, D. (2020). Applying the universal design for learning framework to mathematics instruction for learners with extensive support needs. *Remedial and Special Education, 41*(4), 194–206. https://doi.org/10.1177/0741932519887235	Study tested if embedding UDL in MSBI improves solving multi-step, real-world word problems (e.g., tips, discounts).	Single-subject, multi-probe study testing a universally designed math intervention for middle schoolers with ESN and executive function challenges.	UDL-based MSBI intervention designed to teach percent-of-change word problems to middle schoolers with ESN, increasing access, participa-tion, and success.	Does a universally designed math intervention improve and generalize word problem-solving skills in middle school students with ESN?	Single subject-multiple probe across participants.	N=3 middle school participants receiving special education services; gender and race identified.	IV: MSBI based on UDL, emphasizing multiple means of action and expression.	DVs: (1) Problem-solving skills (points for 6 TA steps, 22/session); (2) Generalization to novel percent-change problems scored the same way.	Findings indicated a functional relationship between the UDL-based intervention and improved mathematical problem-solving skills, highlighting the role of executive functions in learning.	High Quality 1.0
Ünal, Z. E., Forsberg, A., Geary, D. C., & Cowan, N. (2022). The role of domain-general attention and domain-specific processing in working memory in algebraic performance: An experimental approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *48*(3), 348–374. https://doi.org/10.1037/xlm0001117	WM and attentional demands associated with key aspects of algebra: efficiency and accuracy of evaluating expressions, placing ordered pairs in the coordinate plane.	WM process engagement during problem solving in algebraic processing.	Domain-general attention and domain-specific WM (verbal, spatial) support the demands of algebraic tasks.	To what extent do coordinate plane and algebra rely on domain-specific memory versus attention and executive functions?	Quantitative role of WM in symbolic and spatial algebra and related tasks across five experiments.	Five experiments (N≈270; mean age ≈23.8). Mostly college-educated, native English speakers, balanced gender across studies, diverse racial representation in Exp. 3.	Effect of memory load on: 1) expression evaluation 2) expression evaluation + verbal load 3) expression evaluation + spatial load.	Accuracy—specifically accuracy of expression evaluation and memory recall performance.	Algebra tasks rely on attention and verbal/spatial WM, with demands varying by difficulty; instructional design should reduce attentional load/ support LTM.	1.0
Viegut, A. A., Stephens, A. C., & Matthews, P. G. (2024). Unpacking the connections between fractions and algebra: The importance of	Study examined how U's coordination and magnitude knowledge support fractions and	Importance of fraction schemes and U's coordination skills as a predictor of algebra	Hypotheses: U's coordination and fraction schemes correlate with each other, and	How are fractions knowledge and U's coordination related, and how do they uniquely	Quantitative study of middle schoolers examining links between U coordina-	65 8th-grade students−6 attrition = 59 students: 40 schools in Wisconsin, Minnesota,	Covariate: whole number estimation, whole number arithmetic fluency, non-symbolic ration processing,	Algebra knowledge (score on the algebra assessment) in the regression analyses predicting algebra performance.	Viegut's study reinforces fractions–algebra links, highlighting numeric relationships as key	1.0

Title	Study Description	Connection to PoP	Proposed Solution	RQs/ Purpose	Design	Sample/ Participants	IVs	DVs	Results	Strength
fraction schemes and units coordination. *Investigations in Mathematics Learning*, *16*(3), 180–202. https://doi.org/10.1080/19477503.2024.2307805	algebra through multiplicative reasoning	success; identifies areas necessary for student success in secondary math.	with fraction magnitude and arithmetic, beyond covariates.	predict algebra knowledge beyond other math and cognitive skills?	tion, algebra knowledge, and fractions knowledge (schemes, magnitude, arithmetic).	Indiana, Michigan.	nonverbal abstract reasoning, auditory WM.		mechanisms for algebra success.	

Note. Empirical Quality Indicators link: https://docs.google.com/spreadsheets/d/1FHFCteh8I6xCNHAM0atatqyNZ8-nOzFj/edit?usp=sharing&ouid=108517418538803334431&rtpof=true&sd=true

APPENDIX D: EMBEDDED PROCESS THEORY



Note. From "The Relation Between Attention and Memory," by N. Cowan, C. Bao, B. M. Bishop-Chrzanowski, A. N. Costa, N. R. Greene, D. Guitard, C. Li, M. L. Musich, & Z. E. Ünal, (2023). *Annual Review of Psychology, 75*(1), 183–214. https://doi.org/10.1146/annurev-psych-040723-012736. Copyright © 2024 by the author(s).

REFERENCES

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*, 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Almeqdad, Q. I., Alodat, A. M., Alquraan, M. F., Mohaidat, M. A., & Al-Makhzoomy, A. K. (2023). The effectiveness of universal design for learning: A systematic review of the literature and meta-analysis. *Cogent Education, 10*(1), 2218191. https://doi.org/10.1080/2331186x.2023.2218191

Baddeley, A. D. (1986). *Working memory*. Oxford University Press.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (p. 28–61). Cambridge University Press. https://doi.org/10.1017/CBO9781139174909.005

Baldiris Navarro, S., Zervas, P., Fabregat Gesa, R., & Sampson, D. G. (2016). Developing teachers' competences for designing inclusive learning experiences. *Educational Technology & Society*, *19*(1), 17–27.

Barbieri, C. A., & Miller-Cotto, D. (2021). The importance of adolescents' sense of belonging to mathematics for algebra learning. *Learning and Individual Differences, 87*, 101993. https://doi.org/10.1016/j.lindif.2021.101993

Bolman, L. G., & Deal, T. E. (2021). *Reframing organizations: Artistry, choice, and leadership* (7th ed.). Jossey-Bass.

Booth, J. L., & Newton, K. J. (2012). Fractions: Could they really be the gatekeeper's doorman? *Contemporary Educational Psychology, 37*(4), 247–253. https://doi.org/10.1016/j.cedpsych.2012.07.001

Booth, J. L., Newton, K. J., & Twiss-Garrity, L. K. (2014). The impact of fraction magnitude knowledge on algebra performance and learning. Journal of Experimental Child Psychology, 118, 110–118. https://doi.org/10.1016/j.jecp.2013.09

Brantlinger, E., Jimenez, R., Klingner, J., Pugach, M., & Richardson, V. (2005). Qualitative studies in special education. *Exceptional Children, 71*, 195–207. https://doi.org/10.1177/001440290507100205

Center for Applied Special Technology. (2024a). *Design options for strategy development*. https://udlguidelines.cast.org/action-expression/strategy-development/

Center for Applied Special Technology. (2024b). *Universal design for learning guidelines, version 3.0* [graphic organizer]. https://udlguidelines.cast.org/more/downloads

Center for Applied Special Technology. (2025). *Design multiple means of action & expression.* https://udlguidelines.cast.org/action-expression/

Ching, B. H. H., & Li, X. Y. (2024). Early fraction relational reasoning uniquely predicts later algebraic thinking in children: A longitudinal study. *Contemporary Educational Psychology, 79*, 102300. https://doi.org/10.1016/j.cedpsych.2024.102300

Cook, B., Buysse, V., Klingner, J., Landrum, T., McWilliam, R., Tankersley, M., & Test, D. (2014). *Council for Exceptional Children standards for evidence-based practices in special education*. Council for Exceptional Children. https://cecpioneers.exceptionalchildren.org/sites/default/files/2021-04/EBP_FINAL.pdf

Cowan, N., Bao, C., Bishop-Chrzanowski, B. M., Costa, A. N., Greene, N. R., Guitard, D., Li, C., Musich, M. L., & Ünal, Z. E. (2023). The relation between attention and memory. *Annual Review of Psychology, 75*(1), 183–214. https://doi.org/10.1146/annurev-psych-040723-012736

Davies, D. R., & Parasuraman, Raja. (1982). *The psychology of vigilance*. Academic Press.

DeWolf, M., Bassok, M., & Holyoak, K. J. (2015). From rational numbers to algebra: Separable contributions of decimal magnitude and relational understanding of fractions. *Journal of Experimental Child Psychology, 133*, 72–84. https://doi.org/10.1016/j.jecp.2015.01.013

DeWolf, M., Bassok, M., & Holyoak, K. J. (2016). A set for relational reasoning: Facilitation of algebraic modeling by a fraction task. *Journal of Experimental Child Psychology, 152*, 351–366. https://doi.org/10.1016/j.jecp.2016.06.016

Every Student Succeeds Act, 20 U.S.C. § 6301 (2015). https://www.congress.gov/114/plaws/publ95/PLAW-114publ95.pdf

Fuchs, L. S., Compton, D. L., Fuchs, D., Paulsen, K., Bryant, J. D., & Hamlett, C. L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology, 97*(3), 493–513. https://doi.org/10.1037/0022-0663.97.3.493

Fuchs, L. S., & Schumacher, R.F. (2011). *Fraction face-off!* Vanderbilt University.

Fuchs, L. S., Schumacher, R. F., Long, J., Namkung, J., Hamlett, C. L., Cirino, P. T., Jordan, N. C., Siegler, R., Gersten, R., & Changas, P. (2013). Improving at-risk learners' understanding of fractions. *Journal of Educational Psychology, 105*(3), 683–700. https://doi.org/10.1037/a0032446

Fuchs, L. S., Schumacher, R. F., Sterba, S. K., Long, J., Namkung, J., Malone, A., Hamlett, C. L., Jordan, N. C., Gersten, R., Siegler, R. S., & Changas, P. (2014). Does working memory moderate the effects of fraction intervention? An aptitude–treatment interaction. *Journal of Educational Psychology*, *106*(2), 499–514. https://doi.org/10.1037/a0034341

Geary, D. C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities, 37*(1), 4–15. https://doi.org/10.1177/00222194040370010201

Geary, D. C., Boykin, A. W., Embretson, S., Reyna, V., Siegler, R., Berch, D. B., & Graban, J. (2008). *Chapter 4: Report of the task group on learning processes*. Task Group Reports of the National Mathematics Advisory Panel. https://www.ed.gov/media/document/learning-processespdf-89279.pdf

Gravel, J. W. (2018). Going Deep: Leveraging Universal Design for Learning to Engage All Learners in Rich Disciplinary Thinking in ELA. *Teachers College Record: The Voice of Scholarship in Education*, *120*(3), 1–40. https://doi.org/10.1177/016146811812000302

Griful-Freixenet, J., Struyven, K., & Vantieghem, W. (2020). Toward more inclusive education: An empirical test of the universal design for learning conceptual model among preservice teachers. *Journal of Teacher Education, 72*(3), 381–395. https://doi.org/10.1177/0022487120965525

Griful-Freixenet, J., Struyven, K., & Vantieghem, W. (2021). Exploring pre-service teachers' beliefs and practices about two inclusive frameworks: Universal design for learning and differentiated instruction. *Teaching and Teacher Education, 107*, 103503. https://doi.org/10.1016/j.tate.2021.103503

Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2012). The relation between spatial skill and early number knowledge: The role of the linear number line. *Developmental Psychology, 48*(5), 1229–1241. https://doi.org/10.1037/a0027433

Horner, R. H., Carr, E. G., Halle, J., McGee, G., Odom, S., & Wolery, M. (2005). The use of single-subject research to identify evidence-based practice in special education. *Exceptional Children, 71*(2), 165–179. https://doi.org/10.1177/001440290507100203

Jitendra, A. K., Dupuis, D. N., Star, J. R., & Rodriguez, M. C. (2016). The effects of schema-based instruction on the proportional thinking of students with mathematics difficulties with and without reading difficulties. *Journal of Learning Disabilities, 49*(4), 354–367. https://doi.org/10.1177/0022219414554228

Jordan, N. C., Resnick, I., Rodrigues, J., Hansen, N., & Dyson, N. (2016). Delaware longitudinal study of fraction learning: Implications for helping children with mathematics difficulties. *Journal of Learning Disabilities, 50*(6), 621–630. https://doi.org/10.1177/0022219416662033

King-Sears, M. E., Stefanidis, A., Evmenova, A. S., Rao, K., Mergen, R. L., Owen, L. S., & Strimel, M. M. (2022). Achievement of learners receiving UDL instruction: A meta-analysis. *Teaching and Teacher Education*, *122*, 103956. https://doi.org/10.1016/j.tate.2022.103956

Kirkpatrick, J. D., & Kirkpatrick, W. K. (2016). *Kirkpatrick's four levels of training evaluation*. Association for Talent Development.

Kratochwill, T. R., Hitchcock, J. H., Horner, R. H., Levin, J. R., Odom, S. L., Rindskopf, D. M., & Shadish, W. R. (2012). Single-case intervention research design standards. *Remedial and Special Education, 34*(1), 26–38. https://doi.org/10.1177/0741932512452794

Lambert, R., Imm, K., Schuck, R. K., Choi, S., & McNiff, A. (2021). "UDL is the what, design thinking is the how": Designing for differentiation in mathematics. *Mathematics Teacher Education and Development, 23*(3), 54–77. https://files.eric.ed.gov/fulltext/EJ1321118.pdf

Lattin, D. (2024, June 27). *Quality Indicator Checklists.* NTACT: The Collaborative. https://transitionta.org/quality-indicator-checklists/

LeFevre, J., Fast, L., Skwarchuk, S., Smith-Chant, B. L., Bisanz, J., Kamawar, D., & Penner-Wilger, M. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development, 81*(6), 1753–1767. https://doi.org/10.1111/j.1467-8624.2010.01508.x

Meyer, A., Rose, D. H., & Gordon, D. (2014). *Universal design for learning: Theory and practice*. CAST Professional Publishing.

Mind Tools Content Team. (2025). *Kirkpatrick's four level training evaluation model: Analyzing learning effectiveness*. Mind Tools. https://www.mindtools.com/ak1yhhs/kirkpatricks-four-level-training-evaluation-model

Moleko, M., & Mosimege, M. (2021). Flexible teaching of mathematics word problems through multiple means of representation. *Pythagoras, 42*(1), a575. https://doi:https://doi.org/10.4102/pythagoras.v42i1.575

Myers, J. A., Brownell, M. T., Griffin, C. C., Hughes, E. M., Witzel, B. S., Gage, N. A., Peyton, D., Acosta, K., & Wang, J. (2021). Mathematics interventions for adolescents with mathematics difficulties: A meta-analysis. *Learning Disabilities Research & Practice (Wiley-Blackwell), 36*(2), 145–166. https://doi.org/10.1111/ldrp.12244

National Center for Education Statistics. (2025, July 2). *Explore assessment data*. https://nces.ed.gov/nationsreportcard/data/

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. U.S. Department of Education. https://files.eric.ed.gov/fulltext/ED500486.pdf

Nation's Report Card. (2024). *Data_tools*. https://www.nationsreportcard.gov/data_tools.aspx

Onwuegbuzie, A. J., & Corrigan, J. A. (2014). Improving the quality of mixed methods research reports in the field of human resource development and beyond: A call for rigor as an ethical practice. *Human Resource Development Quarterly, 25*, 273–299. https://doi.org/10.1002/hrdq.21197

Onwuegbuzie, A. J., & Poth, C. (2016). Editors' afterword: Toward evidence-based guidelines for reviewing mixed methods research manuscripts submitted to journals. *International Journal of Qualitative Methods, 15*(1). https://doi.org/10.1177/1609406916628986

Organisation for Economic Co-operation and Development. (2023). *PISA 2022 Results (Vol. I): The state of learning and equity in education*. OECD Publishing. https://doi.org/10.1787/53f23881-en

Paas, F., Van Gog, T., & Sweller, J. (2010). Cognitive load theory: New conceptualizations, specifications, and integrated research perspectives. *Educational Psychology Review, 22*(2), 115–121. https://doi.org/10.1007/s10648-010-9133-8

Peng, P., Namkung, J., Barnes, M., & Sun, C. (2016). A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. *Journal of Educational Psychology, 108*(4), 455–473. https://doi.org/10.1037/edu0000079

Pickering, S., & Gathercole, S. (2001). *Working memory test battery for children*. Psychological Corporation.

Powell, S. R., Gilbert, J. K., & Fuchs, L. S. (2019). Variables influencing algebra performance: Understanding rational numbers is essential. *Learning and Individual Differences, 74*, 101758. https://doi.org/10.1016/j.lindif.2019.101758

Rao, K., Ok, M. W., & Bryant, B. R. (2014). A review of research on universal design educational models. *Remedial and Special Education, 35*(3), 153–166. https://doi.org/10.1177/0741932513518980

Reid, G., Grills, A., Mian, N. D., Reid, A. A., Merson, R., & Langer, D. (2017). Using Research-Informed Pedagogical Practices to Maximize Learning in Youth Cognitive Behavioral Therapy. *Evidence-Based Practice in Child and Adolescent Mental Health*, *2*(2), 82–95. https://doi.org/10.1080/23794925.2017.1290511

Rojo, M., King, S., Gersib, J., & Bryant, D. P. (2023). Rational number interventions for students with mathematics difficulties: A meta-analysis. *Remedial and Special Education, 44*(3), 225–238. https://doi.org/10.1177/07419325221105520

Root, J. R., Cox, S. K., Saunders, A., & Gilley, D. (2020). Applying the universal design for learning framework to mathematics instruction for learners with extensive support needs. *Remedial and Special Education, 41*(4), 194–206. https://doi.org/10.1177/0741932519887235

Seethaler, P. M., Fuchs, L. S., Star, J. R., & Bryant, J. (2011). The cognitive predictors of computational skill with whole versus rational numbers: An exploratory study. *Learning and Individual Differences, 21*(5), 536–542. https://doi.org/10.1016/j.lindif.2011.05.002

Siegler, R. S., Duncan, G. J., Davis-Kean, P. E., Duckworth, K., Claessens, A., Engel, M., Susperreguy, M. I., & Chen, M. (2012). Early predictors of high school mathematics achievement. *Psychological Science, 23*, 691–697. https://doi.org/10.1177/0956797612440101

Smith Canter, L. L., King, L. H., Williams, J. B., Metcalf, D., & Rhys Myrick Potts, K. (2017). Evaluating pedagogy and practice of universal design for learning in public schools. *Exceptionality Education International*, *27*(1), 1–16. https://doi.org/10.5206/eei.v27i1.7743

Soares, N., Evans, T., & Patel, D. R. (2018). Specific learning disability in mathematics: A comprehensive review. *Translational Pediatrics, 7*(1), 48–62. https://doi.org/10.21037/tp.2017.08.03

Spektor-Levy, O., & Yifrach, M. (2019). If science teachers are positively inclined toward inclusive education, why is it so difficult? *Research in Science Education, 49*(3), 737–766. https://doi.org/10.1007/s11165-017-9636-0

Spooner, F., Baker, J. N., Harris, A. A., Ahlgrim-Delzell, L., & Browder, D. M. (2007). Effects of training in universal design for learning on lesson plan development. *Remedial and Special Education*, *28*(2), 108–116. https://doi.org/10.1177/07419325070280020101

Star, J. R., Caronongan, P., Foegen, A., Furgeson, J., Keating, B., Larson, M. R., Lyskawa, J., McCallum, W. G., Porath, J., & Zbiek, R. M. (2015). *Teaching strategies for improving algebra knowledge in middle and high school students*. Institute of Education Sciences. https://ies.ed.gov/ncee/wwc/practiceguide/20

Swanson, H. L. (2011). Working memory, attention, and mathematical problem solving: A longitudinal study of elementary school children. *Journal of Educational Psychology, 103*(4), 821–837. https://doi.org/10.1037/a0025114

Swanson, J. M., Schuck, S., Porter, M. M., Carlson, C., Hartman, C. A., Sergeant, J. A., Clevenger, W., Wasdell, M., McCleary, R., Lakes, K., & Wigal, T. (2012). Categorical and dimensional definitions and evaluations of symptoms of ADHD: The SNAP and the SWAN rating scales. *International Journal of Educational and Psychological Assessment, 10*(1), 51–70. https://pmc.ncbi.nlm.nih.gov/articles/PMC4618695/

Trainor, A. A., & Graue, E. (2014). Evaluating rigor in qualitative methodology and research dissemination. *Remedial and Special Education, 35*, 267–274. https://doi.org/10.1177/0741932514528100

Ünal, Z. E., Forsberg, A., Geary, D. C., & Cowan, N. (2022). The role of domain-general attention and domain-specific processing in working memory in algebraic performance: An experimental approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *48*(3), 348–374. https://doi.org/10.1037/xlm0001117

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review, 17*(2), 147–177. https://doi.org/10.1007/s10648-005-3951-0

Viegut, A. A., Stephens, A. C., & Matthews, P. G. (2024). Unpacking the connections between fractions and algebra: The importance of fraction schemes and units coordination. *Investigations in Mathematics Learning, 16*(3), 180–202. https://doi.org/10.1080/19477503.2024.2307805

Witzel, B., & Mize, M. (2018). Meeting the needs of students with dyslexia and dyscalculia. *SRATE Journal, 27*(1), 31–39. http://www.srate.org/JournalEditions/Volume27-1/Witzel_Mize_Manuscript.pdf