ABSTRACT

Mathematical fact fluency, particularly in addition and subtraction, is crucial for students' success in later mathematical concepts and is often a focus of elementary education. Educators are exploring tools to enhance math fluency, such as Reflex Math, a digital program designed to accelerate students' fact fluency through adaptive learning methods. This study investigated the impact of Reflex Math on third-grade students' addition and subtraction fact fluency and its potential correlation with performance on the Pennsylvania System of School Assessment (PSSA) Mathematics test. The research employed a quantitative, quasi-experimental design, involving 55 third-grade students who used Reflex Math during the 2022-2023 school year. Data were collected from Reflex Math usage reports and PSSA Mathematics scores. The analysis revealed that addition and subtraction fact fluency was statistically significant and that Reflex Math positively impacted students over the 2022-2023 school year. The study found weak correlations between PSSA Mathematics scores and fact fluency, suggesting that fact fluency may not be a reliable indicator of performance on PSSA standardized exams. Further research is needed to explore the long-term effects of Reflex Math on broader mathematical concepts and to consider incorporating Reflex Math as a supplementary tool to enhance students' foundational math skills and improve overall academic performance.

Keywords: Fact fluency, addition and subtraction, elementary students, Reflex Math, PSSA

A QUANTITATIVE STUDY OF THE IMPACT OF REFLEX MATH ON THE PENNSYLVANIA SYSTEM OF SCHOOL ASSESSMENT (PSSA)

by

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A Dissertation
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A Quantitative Study of the Impact of Reflex Math on the Pennsylvania System of School Assessment (PSSA)

We, the Dissertation Committee, certify that we have read this dissertation and that, in our judgment, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Education in Educational Leadership.

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DEDICATION

I want to dedicate this dissertation to my lifelong teachers, supporters, and anchors: my parents

Vinh Kim Luu and Phấn Huệ Trần

This work is a testament to your love, encouragement, and sacrifices. Your wisdom has been my guide, your patience a comfort, and your belief in me my strength.

Thank you for teaching me resilience, curiosity, and determination. This achievement is yours as much as it is mine.

With gratitude and love.

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Table of Contents

List of Tables

Chapter 1: Introduction

This chapter outlines the background, justification, and rationale to address the problem of the persistent decline in mathematics performance and to examine the correlation between Reflex Math implementation and improved PSSA Mathematics scores, providing evidence-based insights for instructional design and resource allocation. High-stakes assessments like the Pennsylvania State Standardized Assessment (PSSA) play a pivotal role in evaluating academic proficiency, shaping resource allocation, and informing instructional practices. However, challenges such as the COVID-19 pandemic significantly disrupted foundational learning, particularly in mathematics, leading to widened achievement gaps and long-term academic consequences. Seadog School (a pseudonym), an urban charter school in Pennsylvania, exemplifies these challenges, with 69% of students scoring below the basic level in mathematics during the 2021-2022 school year.

In response to these declines, Seadog School adopted Reflex Math as a universal intervention within its Response to Intervention (RTI) framework. Reflex Math is a research-based, technology-driven program designed to improve students' fluency in basic arithmetic operations, addressing critical foundational skills essential for mathematical proficiency. This study evaluates the effectiveness of Reflex Math in enhancing addition and subtraction fluency over the 2022-2023 school year and examines whether these improvements correlate with higher PSSA Mathematics scores. The study seeks to contribute evidence-based insights into the potential of using gamified computer assisted learning tools like Reflex Math to address foundational skill gaps and improve standardized testing outcomes. The findings hold implications for educators, administrators, and policymakers, providing data-driven

recommendations for instructional design, intervention strategies, and resource allocation to enhance students' mathematical achievement.

Background

High-stakes testing can significantly impact funding, school ratings, and even employment decisions for educators (Ashadi & Rice, 2016; Heilig & Darling-Hammond, 2008). In Pennsylvania, the Pennsylvania State Standardized Assessment (PSSA), serves as a crucial tool for evaluating students' academic proficiency in third through eighth grade. Administered annually in late spring, the PSSA assesses students' reading, writing, and mathematics achievement, aligning its test questions with the Pennsylvania Common Core Standards in English Language Arts and Mathematics. This standardized test not only measures student achievement but also plays a pivotal role in holding educators and schools accountable for the quality of education provided throughout the academic year. Educators are required to use the Pennsylvania Core Standards to guide their daily lessons because they provide clear learning objectives, ensuring focused and relevant instruction. When lessons and activities are aligned with these standards, consistency and equity are promoted statewide. School administrators rely on PSSA data to make decisions regarding the quality of different programs and curricula. For example, they determine which interventions and supports appear to be effective or ineffective in bridging the achievement gap and improving students' overall aptitude in mathematics and reading.

During the 2019-2020 school year, the PSSA was canceled due to the disruptions caused by the COVID-19 pandemic. Impellizeri et al. (2022) states that students in Pennsylvania experienced significant disruptions such as extended periods of virtual learning, limited access to in-person instruction, and different amounts of parental support. Kuhfeld et al. (2020) found that

students preserved only 37% to 50% of their average learning gains in mathematics during the 2019-2020 school closures, highlighting the considerable impact of learning loss on academic attainment. These setbacks are critical and have long-term consequences for children's academic development. Such contextual factors influenced students' foundational learning experiences and their performance on assessments (Storey & Zhang, 2024), including the PSSA. These issues, worsened by the digital divide, particularly in areas with low technology access (Kumi-Yeboah et al., 2023), which impacted students in urban areas of eastern Pennsylvania (Impellizeri et al., 2022) and widened existing imbalances resulted in significant learning loss (A'yun et al., 2022).

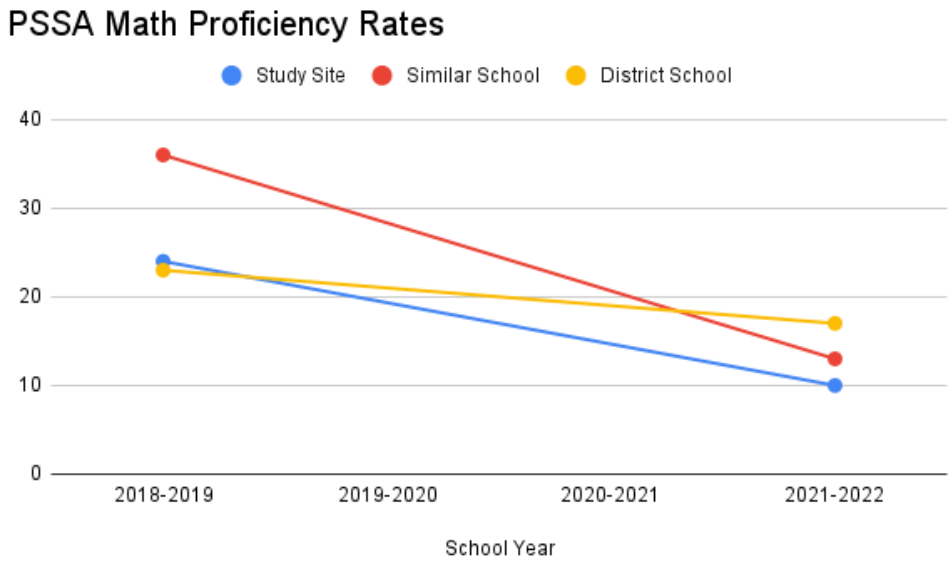
Statement of the Problem

The COVID-19 pandemic has impacted students' foundational learning, particularly in mathematics (Conto et al., 2021), which is evident in the challenges faced by students impacted by school closures (Morten at al. For example, Conto et al. (2021) found that the pandemic negatively impacted second and third grade students' performance on mathematics standardized assessments. Schools were thus forced to respond to by mitigating the learning loss and reducing performance parities on students' future performance on the PSSA.

One urban charter school in eastern Pennsylvania, Seadog School (pseudonym) was particularly impacted by the pandemic. The administrators at the Seadog School reviewed the PSSA Mathematics data and noticed a significant decline of 14% since the 2018-2019 school year. The standardized mathematics test data for the Seadog School during the 2021-2022 school year showed 69% of students scoring below the basic level (see Figure 1).

Figure 1

PSSA Math Proficiency Rates



Administrators within the school recognized the problem of declining mathematical performance on the PSSA Mathematics assessment and chose to use a Response to Intervention (RTI) framework to ensure instruction and support were provided to all students in the general education setting. RTI is a tiered framework featuring interventions that escalate in intensity across tiers (Friedman, 2010). It is important to consider RTI tiers in terms of their role as points of prevention. There are three tiers of prevention. Primary prevention is delivering high-quality learning to all students in the standard classroom setting (Friedman, 2010). For students unresponsive to this framework, secondary prevention offers interventions to enhance the classroom program. For students unresponsive to secondary prevention, a far more intensive and adaptable form of tertiary prevention is administered (Friedman, 2010). Reflex Math became the universal intervention at the Seadog School, and thus, this study sought to determine if the Reflex Math program positively impacted students' scores on the PSSA Mathematics assessment

by examining students' scores before and after interventions using Reflex Math were implemented.

Reflex Math uses research-proven methods and innovative technology to help students across multiple grade levels score higher and grow faster than their peers on standardized tests and assessments (Explore Learning, 2024a). This helps students master basic skills like addition, subtraction, multiplication, and division through engaging and fun games. Reflex Math focuses on mathematics fluency, which is the ability to solve math problems correctly and quickly. Fact fluency is a foundational skill crucial for students' mathematical proficiency, and understanding the impact of specific educational interventions like Reflex Math is essential for educators and policymakers. Although research has explored the impact of learning loss due to closures during the pandemic (Impellizeri et al., 2022), there is a gap in research that explores students who started kindergarten during the 2020-2021 school year and their addition and subtraction fluency. Likewise, little research has explored to what extent Reflex Math impacts PSSA achievement scores.

Purpose of the Study

This study examined the level of correlation between the implementation of the Reflex Math program for one year and improved student mathematics achievement as measured by PSSA Mathematics scores. The school where this study took place, Seadog School, implemented Reflex Math during the 2022-2023 school year. The school serves students in grades K through 8, and there were 837 students enrolled at the Seadog School during the 2022-2023 school year. The school used Reflex as a form of universal intervention in the general classroom because students continued to experience difficulties in mastering essential mathematical skills (Korbey, 2023).

Research Questions

To guide this quasi-experimental quantitative study, the researcher explored two research questions (RQ).

RQ1. Does fact fluency for addition and subtraction significantly improve for third-grade students who use Reflex Math over the 2022-2023 school year?

RQ2. Is there a correlation between students' fact fluency in addition and subtraction and their PSSA scores?

Hypotheses

$H1_0$. There is no statistically significant improvement in addition and subtraction fact fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

$H1_1$. There is a statistically significant improvement in addition and subtraction fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

$H2_0$. There is no correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

$H2_1$. There is a positive correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

Significance of the Study

This study evaluated the effectiveness of Reflex Math in enhancing students' fact fluency in addition and subtraction over a single school year and examined whether these improvements correlated with higher PSSA Mathematics scores. Research highlights the critical importance of achieving automaticity in basic arithmetic operations (addition, subtraction, multiplication, and division) by the end of third grade, as students lacking this foundation often struggle with

advanced mathematical concepts due to increased cognitive demands (Berrett & Carter, 2017; Parkhurst et al., 2010).

By comparing students who frequently used Reflex Math with those who did not, the study provides a nuanced perspective on the program's potential to influence standardized test outcomes. These findings could inform evidence-based decision-making for curriculum design and educational policies, offering valuable insights into the role of technology-assisted interventions in supporting student success.

PSSA scores, which serve as a comprehensive measure of academic proficiency, are examined to determine whether Reflex Math's focus on fact fluency translates into broader academic achievement. This analysis contributes to pedagogical knowledge by identifying effective teaching strategies for improving students' mathematical skills and empowering educators with data-driven insights for continual instructional improvement. Ultimately, the study's results hold significant implications for guiding educators and administrators in integrating technology-assisted learning tools like Reflex Math into their curricula.

Limitations and Delimitations

This study had several limitations that may have affected the generalizability of its findings. The sample size was restricted to a single school, which may not adequately represent the broader population, limiting the applicability of the results to other educational settings. Additionally, data were collected across only two PSSA testing years, which may not capture variations in student performance over time or across different cohorts. Furthermore, the intervention period for using Reflex Math was constrained to just one year, potentially limiting the effectiveness of the program and the ability to assess long-term impacts on student learning.

These factors highlight the need for caution when interpreting the results and suggest that further research is needed to explore these findings in more diverse and extended contexts.

Delimitations for this study included the specific focus on a single school and its student population, which were chosen to streamline the research process and maintain a manageable scope. The decision to collect data exclusively from two PSSA testing years concentrated on recent performance trends rather than a broader historical perspective. Additionally, the study was limited to assessing the impact of Reflex Math within one academic year to evaluate its immediate effects on student learning. These delimitations were intended to provide a clear framework for the study, ensuring that the research remained focused and feasible while also acknowledging the inherent boundaries of the investigations.

Researcher Assumptions

In conducting this quasi-experimental quantitative study, several assumptions were made to guide the research design and interpretation of results. First, it was assumed that the chosen instruments for measurement, including the PSSA tests and the Reflex Math program, were valid and effectively captured the constructs of interest, such as student performance and engagement. By relying on these established tools, the study presumed that they provide a consistent framework for evaluating educational outcomes. Another key assumption was that external factors affecting student performance, such as socioeconomic status, prior academic achievement, and classroom testing environment, remained relatively stable throughout the study period. This assumed that these variables did not significantly fluctuate and impact the results during the specified testing years. Moreover, the researcher assumed that the Reflex Math program would be implemented uniformly across the participating students within the designated time limit, ensuring a consistent intervention experience. These assumptions were vital for the

integrity of the study's results; however, they also highlight the necessity for caution in interpreting the results, as deviations from these assumptions could influence the study outcomes.

Summary

This chapter outlined the background, justification, and rationale for addressing the persistent decline in mathematics performance and examining the correlation between Reflex Math implementation and improved PSSA Mathematics scores. High-stakes assessments, like the PSSA, significantly influence instructional practices, resource allocation, and educational accountability, underscoring the importance of effective interventions to support student success. The COVID-19 pandemic exacerbated learning gaps, particularly in mathematics, prompting schools like Seadog School (pseudonym) to adopt programs such as Reflex Math to improve foundational arithmetic skills and overall academic performance. This study investigated the effectiveness of Reflex Math in enhancing addition and subtraction fluency and its potential impact on PSSA Mathematics scores, offering critical insights for educators and policymakers.

The next chapter explores the potential impact of Reflex Math on student performance as it is essential to examine existing research on the role of educational interventions in improving mathematics fluency and standardized test outcomes. The literature review provides a comprehensive overview of relevant studies that highlight the importance of early mathematics fluency, the effectiveness of technology-assisted learning tools like Reflex Math, and the broader implications of such interventions on academic achievement. By synthesizing findings from prior research, this review contextualizes the study's objectives and identifies gaps in the literature, guiding the investigation into whether Reflex Math can effectively improve PSSA Mathematics scores.

Definition of Key Terms

The following terms are defined to assist the reader with the comprehension of the study:

Adequate Yearly Progress (AYP). An individual state's measure of yearly progress toward achieving state academic standards, as described in the NCLB legislation (USDE, 2021). AYP is the minimum level of improvement that states, school districts, and schools must achieve each year (Ravitch, 2007).

Automaticity. Automatic recall of facts without conscious control (Hasselbring et al., 1988).

Computer-Assisted Instruction (CAI). A key element of a technology-based learning environment that helps improve student achievement and build/enhance student motivation (Anugrah et al., 2022).

Educational Technology (Ed Tech). The introduction of information and technology tools in teaching and learning (Kim et al., 2023)

Every Student Succeeds Act (ESSA). The federal K-12 education law of the United States. ESSA was signed into law in 2015 and replaced the previous education law called "No Child Left Behind." ESSA extended more flexibility to States in education and laid out expectations of transparency for parents and for communities (*What Is the Every Student Succeeds Act?*, n.d.).

Evidence-Based Practice. Research-supported interventions and instructional methods that are recognized, shared, and accepted as beneficial (Kazdin, 2008).

Fluency. Mathematics fluency is the automatic recall of basic mathematics facts, which is measured by whether students' responses are rapid and accurate (Huinker, 2018).

Formative Assessment. Any assessment used by educators to evaluate students' knowledge and understanding of content. It is used to adjust further instructional practices accordingly to improve student achievement in that area (Ravitch, 2007). Also defined as any activity that provides sound feedback on students' learning (Marzano, 2006).

Gamification. The use of game design elements in non-game contexts (Deterding et al., 2011)

No Child Left Behind (NCLB). The reauthorization of Elementary and Secondary Education Act that increased accountability for states; a standards-based federal policy that uses high-stakes state assessments to measure student performance and school accountability (Cho & Kingston, 2011).

Mathematics Fact Fluency. The ability of students to recall basic mathematical problems with speed and accuracy and without hesitation (Cozad & Riccomini, 2016; Hunker, 2018).

Reflex Math. A computerized math fact fluency program that covers fact fluency from initial acquisition to automaticity while adapting to a student's ability level using fun and motivating games (Cholmsky, 2011).

Response to Intervention (RTI). A system of supports that schools put in place to provide high-quality education to students with disabilities. It was originally developed as an overall framework for prediction, remediation and prevention of negative outcomes common for students with disabilities ("Understanding Response to Intervention (RTI) and Multi-Tiered System of Support (MTSS)," 2001)

Student Achievement. A definitive measure of a student's academic growth through norm-referenced and criterion-referenced test batteries (Ravitch, 2007)

Chapter 2: Literature Review

This research explored the intersection of several key factors impacting mathematics education in contemporary classrooms. It focused on Cognitive Load Theory and its application to teaching mathematics fact fluency, with an emphasis on strategies designed to enhance fluency through Response to Intervention (RTI) frameworks. Additionally, the study examined the role of Common Core Standards in shaping mathematics instruction, while considering the evolution of educational technology and its growing influence in the classroom. Considering the COVID-19 pandemic and its profound effects on learning, particular attention was given to the resulting learning loss in math and how gamification and tools like Reflex Math have emerged as potential solutions to address these challenges. By synthesizing previous literature on these themes, this chapter aimed to provide a comprehensive understanding of how educational practices and technology can mitigate the disruptions caused by the pandemic while enhancing student outcomes in math.

Cognitive Load Theory

Cognitive Load Theory (CLT) (Gagne, 1983) illustrates the importance of automaticity in mathematics as it is crucial for future mathematical success because it is directly linked to decreased working memory demands and, thus, reduced cognitive load (Berrett & Carter, 2017; Parkhurst et al., 2010) The automatic recall of fundamental mathematical knowledge alleviates cognitive strain by removing unnecessary calculations and directing cognitive resources toward the more intricate components of mathematical issues (Parkhurst et al., 2010). According to Gagne (1983), human learning is inherently meaningful, involves converting physical stimulation into information, includes mental processes like attention and reinforcement for

transforming information, incorporates control processes such as rehearsal and retrieval, and depends on external stimulation being transformed into learnable information.

CLT has significant implications for education and instructional design. By understanding the importance of attention, motivation, memory, and problem-solving skills, educators can devise strategies that optimize these cognitive processes to enhance learning outcomes (Dunlosky et al., 2013). Additionally, recognizing the role of prior knowledge and mental frameworks can help educators tailor their instructional methods to build upon students' existing understanding, leading to more effective knowledge construction (Saunders, 2020). Moreover, the idea that learners actively select, process, and integrate information aligns with personalized learning. This approach recognizes the individual differences among learners and seeks to provide customized learning experiences that cater to their unique cognitive abilities and preferences (Dunlosky et al., 2013). By implementing CLT principles, educators can create environments that foster deep engagement and meaningful learning experiences for every student (Hultberg et al., 2018). If students can reduce the number of steps needed, the cognitive load is reduced, therefore, allowing students to complete multi-step problems faster and with less stress, they are more likely to have increased performance on standardized assessments, like the Pennsylvania System of School Assessments (PSSA).

Federal Regulations on Demonstrating School Effectiveness

The current state of assessing students' achievement is rooted in historical precedence at the federal level (Williams & Welsh, 2017). President Lyndon Baines Johnson signed The Elementary and Secondary Education Act (ESEA) into law in 1965, aimed at mitigating the inequities in education by providing "full educational opportunity" (Brown, 2010, para. 1) in response to the Civil Rights Movement (Paul, 2022). ESEA granted federal subsidies for

textbooks and library books, financing for special education centers, new awards to districts serving low-income students, and scholarships for low-income college students (Brown, 2010). The law also provided federal subsidies to state education departments to raise the standard of elementary and secondary education (Brown, 2010). In 2002, under President George W. Bush, the 107th Congress revised ESEA to address the growing achievement gap by shifting the focus of education to accountability, flexibility, and school choice through the passage of the No Child Left Behind Act of 2001 (NCLB) (Holcomb & McIntosh, 2011; NCLB, 2002). Under NCLB, states were mandated to maintain academic standards, develop state-wide assessment systems, and consistently make adequate yearly progress (AYP), or their schools could lose federal funding (Holcomb & McIntosh, 2011). It was necessary to create annual state progress targets that mandated all student groups attain proficiency within 12 years (Holcomb & McIntosh, 2011; PA Department of Education [PDE], 2007). The AYP measured whether a school or district makes sufficient annual progress toward the goal of 100% proficiency by 2014. NCLB targeted the achievement gaps between different demographic groups, such as students from low-income families and minority groups (Klein, 2023), and included provisions related to teacher qualifications. Schools were required to employ highly qualified teachers, promoting the importance of teacher quality in student success (Klein, 2023).

In many ways, NCLB was a massive advancement for the children of the United States, introducing a system of accountability that required states to set standards for student proficiency in reading and mathematics. The Common Core State Standards Initiative, referred to as the Common Core and written between 2006-2010, was a state-based effort to anchor U.S. public education in a shared set of high academic standards. The Common Core were meant to be clearer and more concise than the standards written under NCLB (Kornhaber et al., 2014), help

identify areas of improvement, and set benchmarks for student achievement, which was underpinned through rigorous data collection and analysis. Schools were required to demonstrate students' mastery of the content and report the results so that educators, administrators, and policymakers could identify trends, weaknesses, and areas that needed improvement (Klein, 2023). As time passed, the rigid demands of NCLB became increasingly impractical for schools and teachers to demonstrate students' proficiency (Shapiro & Thompson, 2007).

The Every Student Succeeds Act (ESSA) was signed into law by the President Obama Administration in December of 2015. According to the U.S. Department of Education (USDE, 2024), "Over time, NCLB's prescriptive requirements became increasingly unworkable for schools and educators" (para. 2), and as a result, the Obama administration focused on developing a more effective law that emphasized as its primary objective adequately preparing every student for achievement in both college and their future careers. The shift to school accountability has been critical in ensuring a quality education for all children (USDE, 2024). The transition from NCLB to ESSA prompted significant adjustments for educators and administrators. This led to the termination of the Adequate Yearly Progress (AYP) system, which relied heavily on standardized test scores to evaluate schools. ESSA mandated accountability plans for states and districts but allowed greater flexibility and control over the measures utilized. Some other measures of effectiveness included the achievement and growth of English Language Learners, participation in college and career readiness programs, graduation rates, and measuring school climate and culture. Despite having a broader selection of measures, standardized test scores are still weighted more than other indicators (Klein, 2015)

Pennsylvania Common Core Standards

The Pennsylvania Board of Education adopted the Core Standards in July of 2010. A group of Pennsylvania educators created the new standards to reflect both the content and rigor of the Common Core and the organization and design of Pennsylvania Academic Standards (Commonwealth of Pennsylvania, n.d.-a). The PK-12 PA Core Standards for Mathematics cannot be viewed or addressed in isolation, as each standard is dependent on or may lead to multiple standards across grades; thus, educators must be familiar with both the standards preceding and following a specific grade level. These new standards reflect instructional shifts that are not possible without an integrated emphasis on material and practice. Standards are broad assertions that describe what a proficient math student should know and be able to do (Commonwealth of Pennsylvania, n.d.-a). The Pennsylvania Assessment Anchors and Eligible Content closely align with the updated standards and are a helpful resource for more information.

The standards emphasize procedural abilities and conceptual comprehension, which are critical for ensuring that students learn and apply the fundamental information required for success at advanced levels (Commonwealth of Pennsylvania, n.d.-a). The K-5 standards establish a robust foundation in whole numbers, addition, subtraction, multiplication, division, fractions, and decimals, enabling students to effectively engage with more complex mathematical concepts and methods, facilitating their progression into application (Commonwealth of Pennsylvania, n.d.-a). They offer comprehensive direction to educators on effectively addressing topics such as fractions, negative numbers, and geometry, ensuring a seamless progression from one grade to the next. After building a solid foundation, students are better prepared for hands-on learning in geometry, algebra, probability, and statistics by the seventh and eighth grades. High school

students focus on standards that highlight the ability to apply mathematical concepts to real world challenges (Commonwealth of Pennsylvania, n.d.-a).

According to the Pennsylvania Standards Aligned System, second-grade students are engaged with Standard CC.2.1.2. B.3, which requires the use of place value comprehension and operational properties to perform addition and subtraction within 1000 (Commonwealth of Pennsylvania, 2024). In third grade, students focus on Standard CC.2.2.3. A.3, which requires the demonstration of fluency in multiplication and division (Commonwealth of Pennsylvania, 2024). Since the fluency standards are sequential, they cannot be viewed in isolation. Consequently, a gap in foundational skills is established by the conclusion of the third grade if students fail to satisfy the standards.

Pennsylvania System of School Assessments

Students in the state of Pennsylvania who attend public and charter schools are assessed annually by the Pennsylvania System School Assessment (PSSA), which is a standards-based, criterion-referenced assessment that "provides students, parents, educators and citizens with an understanding of student and school performance related to the attainment of proficiency of the academic standards" (Pennsylvania Department of Education [PDE], n.d., para. 1). The Pennsylvania Department of Education assesses every student annually in third through eighth grades in English Language Arts and mathematics. Additionally, students in fourth through eighth grade take science assessments. Schools receive individual student scores that help them identify areas needing improvement, enabling schools and districts to make data-driven decisions regarding curriculum and instruction and facilitate effective planning (PDE, n.d.).

Pennsylvania developed its annual statewide assessment in following requirements set by NCLB Act, ESSA, and the Race to the Top grant. According to PDE (n.d.), this assessment is

based on specific standards and criteria, helping students, parents, educators, and citizens understand how effectively students and schools meet academic expectations. These standards encompass English Language Arts, mathematics, and science and technology, outlining what students should know and be able to do at various grade levels. School districts can create flexible curricula and teaching methods to ensure students meet or exceed these standards. In the requirements outlined in the 4.51(a)(4) of the Pennsylvania School Code, Pennsylvania states that all PSSA assessments administered will be standards-based and criterion-referenced (Commonwealth of Pennsylvania, n.d.-b). The PSSA was canceled during the 2019-2020 school year due to the impact of the COVID-19 pandemic on schools.

Mathematics Fact Fluency and Automaticity

Students are better equipped to demonstrate their knowledge of mathematics standards when they can recall basic math facts in all four operations (addition, subtraction, multiplication, and division) quickly and effortlessly. This automaticity in mathematics fact fluency enables students to focus on higher-order problem-solving skills and conceptual understanding (Explore Learning Reflex, 2024b). Students are considered fluent when they can accurately respond to a fundamental mathematical fact issue within two seconds (Hoboken Public School District, n.d.). When students can automatically recall these things, they have reached a competency that enables retrieval from long-term memory without conscious effort or attention (Vicuna & Vicuna, 2024). Researchers commonly agree that mathematics fact fluency is essential for later success in more complex mathematics such as algebra (Geary, 2011; Nelson et al., 2016). The development of fluency is a sequential process in which a student evolves from fundamental counting to computation and subsequently to automatic retrieval. A student who attains greater fluency abandons traditional mathematical methods, such as finger counting, and ultimately

depends solely on semantic memory (Berrett & Carter, 2017), and such students typically possess enhanced cognitive capacity for understanding more intricate topics (McCallum et al., 2006; Poncy et al., 2006). Studies indicate that fluency is essential for mathematics at the primary level and even later to recall when learning more concepts in math. Automaticity frees working memory so students can use it to solve problems and learn new concepts (Geary, 1994). When students reply in 45 milliseconds or less, they are regarded to have automaticity-specific mathematical facts (Crawford, n.d.).

Automaticity in mathematics not only allows students to solve problems quickly, but it also frees up cognitive resources for higher-level thinking. This means that students who have mastered basic math facts can more easily tackle complex problems and excel on challenging assessments (Baker & Cuevas, 2018). Achieving automaticity can boost students' confidence and motivation, as they feel more capable and competent in their mathematical abilities. Research indicates that students with strong mathematical automaticity are better equipped to apply their skills in real-world situations, leading to improved critical thinking and analytical skills (Baker & Cuevas, 2018, Pegg et al., 2005) This automaticity serves as a gateway to deeper understanding and mastery of mathematical concepts, paving the way for academic success (Baker & Cuevas, 2018).

The Pennsylvania Common Core State Standards (n.d.) states that by the end of second grade, students should have automaticity with basic addition facts. By the end of third grade, they should achieve automaticity with basic facts for all four math operations, extending to multi-digit figures by fifth grade. The Pennsylvania Common Core State Standards (n.d.) states that by the end of second grade, students should have automaticity with basic addition facts. By the end of third grade, they should achieve automaticity with basic facts for all four math

operations, extending to multi-digit figures by fifth grade. The benefits of responding quickly, precisely, and instinctively include finishing more complex material and performing better on advanced accomplishment examinations (Sarrell, 2014).

Mathematics Fact Fluency Strategies

Achievement disparities are apparent across various socioeconomic groups and students with differing learning capacities (Broer et al., 2019). Researchers, school officials, and educators highlight evidence-based ways to fight the decline in mathematics performance, particularly the critical impact of proper practice time on student achievement (Hillmayr et al., 2020). Drill and practice, along with explicit instruction on how to solve math problems procedurally, are evidence-based and effective tactics (Korbey, 2023). Focusing on drill and skill alone is insufficient. For students to develop a deep and meaningful understanding of mathematics, they have to also apply their mathematical knowledge in real-world situations and explore different approaches to solving problems. Balancing both drill and skill practice with problem-solving activities is crucial for establishing a strong foundation in mathematics (Lehtinen et al., 2017). While rote memorization and procedural fluency are important, they necessitate conceptual understanding to excel in the subject (Foster, 2017). Simply drilling students on mathematical procedures and techniques without also teaching the underlying concepts can result in a limited and inflexible approach to problem-solving (Lehtinen et al., 2017).

Effective fluency-building instruction involves incorporating modeling, providing ample drill and practice with high response rates, including immediate and corrective feedback, and incorporating an appropriate ratio of known to unknown facts (Riccomini et al., 2017). However, incorporating these facets of effective instruction in classrooms can be challenging due to the

lack of adequate practice for students to develop math fact fluency. Teachers may not be able to develop their own mastery materials and allocate adequate time for fluency building, limiting students' opportunities to become fluent with math facts (Berrett & Carter, 2017).

Practicing math facts should focus on appropriate ratios of known to unknown facts, which can be difficult due to students' acquisition rates and the varying ratios over time (Riccomini et al., 2017). For example, students with disabilities may require a 9:1 ratio initially, which can be lowered to 3:1 as mastery increases. Instructional methods that adapt to a student's ability level and specific needs are more likely to be effective in teaching basic math facts (Riccomini et al. 2017). Before formal schooling, children use counting to solve simple sums, initially with support such as manipulatives or fingers, but gradually without support. Efficiency increases with grade, moving from counting sets to counting from larger numbers. The fundamental issue is that research fails to provide a definitive methodology for assisting students in mastering their mathematical knowledge (Sawchuk, 2023).

Sawchuk (2023) conducted interviews with practicing instructors, reviewed numerous studies, and interviewed cognition researchers to learn about their techniques for addressing fact fluency and managing this aspect of the mathematics puzzle in conjunction with the other activities that should take place in the elementary mathematics classroom. The researcher suggests that mathematics fact fluency practice can and should be a purposeful component of the classroom and that the practice should be relatively brief but consistent, well-sequenced, and avoid attempting to do too much at once (Sawchuk, 2023). The distinction between drills and practice is a critical component of imparting math facts. A drill is repetitive, while practice is more problem-based and necessitates problem-solving strategies. Students do not benefit from being obligated to perform drill exercises repeatedly for extended periods of time because it can

give students an idea that thinking is not involved when computing facts (Bielsker et al., 2001; Olson, 2021). An effective approach is to proceed through the fact families in a logical manner rather than beginning at zero and concluding at nine (Olson, 2021). Students can perform simple tasks to develop confidence and understand the patterns of facts. It is also logical to acquire knowledge of the three-fact family prior to the six-fact family, as numerous numbers are similar and build upon one another (Olson, 2021). By developing a systematic approach and building on knowledge of related fact families, students can improve their understanding of mathematical concepts and build confidence in their abilities(Foster, 2017). This method allows for a deeper comprehension of facts rather than just rote memorization. Oftentimes, school administrators will allocate support in this area under the Response to Intervention (RTI) model.

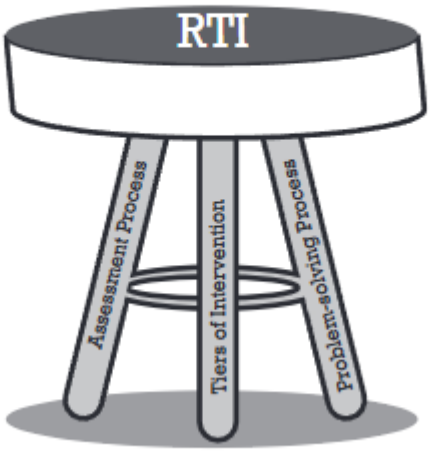
Response to Intervention (RTI)

Response to Intervention (RTI) is well-established as best practices for making data-based decisions on intervention needs and preventing school-wide academic difficulties (Wang et al., 2024). RTI is a multi-tier approach to the early identification and support of students with learning and behavior needs. It provides targeted interventions at increasing levels of intensity to help struggling students succeed academically and aims to prevent academic failure through early intervention and ongoing progress monitoring. Searle (2010) describes it as a stool with three legs (see Figure 2). The first leg focuses on an assessment, the second leg has the different interventions available to implement, and the third leg is a problem-solving process. The assessment leg involves screening all students to identify those who may be at risk for academic difficulties. It uses data from three main assessments. One source of data is a universal screener, and it helps identify high-priority areas of concern, answering fundamental questions about keeping and updating students, and identifying gaps between expected outcomes and actual

performance. Diagnostic assessments refine this data, while progress monitoring provides continuous feedback and strategy changes (Searle, 2010).

Figure 2

Representative Structure of the RTI Process



Note. This figure appears in "What Every School Leader Needs to Know About RTI" by M. Searle, 2010.

The leg representing interventions includes a range of research-based strategies tailored to the specific needs of each student. There are three levels of support identified. Tier 1 offers research-based classroom practices that can help 80-90 percent of kids succeed without additional intervention. Tier 2 offers moderate-intensity interventions that enhance Tier 1 tactics and are administered to groups of three to six students. Five to 10 percent of students may require support at this level. Tier 3 offers intensive interventions for groups consisting of one to three students. Typically, one to five percent of students require support at this level (Searle, 2010). The problem-solving process involves a collaborative approach among teachers, parents, and other professionals to determine the best course of action for each student. Together, these

three legs form a strong foundation for supporting student success and promoting positive academic outcomes (Fuchs & Fuchs, 2006).

By using a tiered system of interventions, students receive targeted instruction and support based on their individual needs. This proactive approach identifies and addresses learning gaps early on, ultimately leading to improved academic outcomes for all students (Wang et al., 2024). Additionally, the RTI framework allows educators to monitor progress closely and make data-driven decisions to ensure that each student makes adequate academic growth (Wang et al., 2024).

COVID-19 Pandemic and Learning Loss

The COVID-19 pandemic significantly influenced educational systems, resulting in considerable learning losses, particularly in mathematics in the United States (Morton et al., 2022). These setbacks have long-term effects on children's academic development and prospects. According to Kuhfeld et al. (2020), children only preserved 37% to 50% of their usual learning gains in mathematics during the 2019–2020 school closures. This drastic cut highlights the urgency of addressing the pandemic-exacerbated educational deficiencies. In a typical school year, U.S. students have historically made learning improvements in mathematics of roughly .56 standard deviations (Schult et al., 2022). However, these achievements have regressed due to the pandemic, especially for vulnerable communities (Tan et al., 2023). For example, learning deficits were more pronounced for students from low-income families and those attending underfunded schools. Research indicates that Black and Latino students, in comparison to their counterparts, experience an approximate deficit of six months in arithmetic proficiency (Dorn et al., 2020). This gap illustrates that the pandemic compounded pre-existing achievement inequities by underscoring the correlation between socioeconomic status and educational

outcomes. The lack of direct teacher assistance and peer contact in remote learning has intensified students' understanding of mathematics since disruptions have hindered engagement with complex mathematical concepts (Engzell et al., 2021).

The Evolution of Educational Technology

The lack of interaction in the classroom and the challenges of engaging students in a virtual environment have been widely documented (A'yun et al., 2022), with many educators needing help to maintain student motivation and participation (Sahu, 2020). Integrating technology into education has been both a challenge and an opportunity. The pandemic has increased the adoption of digital tools in education, asking teachers to explore innovative pedagogical strategies to engage students in online learning environments (Lin et al., 2023). For instance, virtual manipulatives in mathematics education have gained traction as educators seek to replicate hands-on learning experiences in a digital format (Kabel et al., 2021).

The COVID-19 pandemic has significantly accelerated the evolution of educational technology (EdTech) and fundamentally altered teaching and students' educational experiences worldwide (Santos, 2022). The digital revolution provided innovative methods for delivering mathematics training and enhancing academic performance (Roblyer & Doering, 2009). The benefits of EdTech include personalized instruction, immediate feedback, targeted skill development, and improved academic outcomes (Duhon et al., 2012). Additionally, technology has enabled educators to create immersive learning experiences without the constraints of traditional field trips, utilizing conversational interfaces for practical language training (Spector, 2001). As schools continue to harness these technological advancements, they must also confront the pressing issue of learning loss, particularly in the wake of global disruptions to traditional

schooling. The COVID-19 pandemic has brought this challenge into sharp focus, creating the need for innovative approaches to address the gaps in student knowledge and skills.

Strategies to Address Learning Loss

The pandemic has also redefined the landscape of educational engagement. Students were no longer limited to face-to-face interactions, and the option for hybrid learning has allowed them to choose their preferred mode of education. This flexibility has fostered greater student autonomy and motivation, allowing learners to take ownership of their educational journeys (Hodge et al., 2020). The ability to learn from anywhere, combined with the wealth of online digital resources, has transformed educational experience and made learning more accessible to diverse populations. Moreover, while research on technology's impact on learning is expanding, considerable debate remains about its effectiveness in enhancing student achievement (American University School of Education, 2020). Some studies suggest that the mere presence of technology does not guarantee improved outcomes. Instead, the thoughtful integration of technology into pedagogy makes a difference (Cauley et al., 2009).

The rapid transition to remote learning during the pandemic underscored both the potential advantages and challenges of digital tools in education. Although online learning provides flexibility, it also reveals how unstable internet connections impede effective learning (A'yun et al., 2022). This transition to remote learning necessitated a significant increase in technological skills among educators and students alike. The digital divide became a crucial concern, particularly in areas with limited technological access, emphasizing the need for equitable resource distribution (Kumi-Yeboah et al., 2023).

Although technology is vital for online learning, effective educational practices must accompany it to address systemic challenges (Zhang et al., 2022). The pandemic prompted

educators to rethink their methodologies, recognizing technology as essential for teaching mathematics and integrating digital resources into their practices (Amedu & Hollebrands, 2022).

Blended learning, which combines traditional and online methods for effective remote instruction, became increasingly popular (Mukavhi & Brijlall, 2021). This approach offered the flexibility to cater to diverse learning styles and paces, allowing students to engage with content more deeply. Furthermore, the flipped classroom model gained traction, promoting interactive and engaging learning experiences (Villarica, 2023); however, the shift to online learning also highlighted gaps in digital instructional practices, underscoring the need for ongoing professional development to empower educators (Teixeira et al., 2023). By doing so, educators can prepare students for the complexities of the 21st century, ensuring that they acquire knowledge and develop the skills and resilience necessary to thrive in an increasingly digital world (Lee & Hancock, 2023).

Gamification

In recent decades, rapid technological advancements have made digital game devices more accessible, and the tools for creating these games have become much easier to use (Li et al., 2024). In the context of assisted learning, games possess unique characteristics, such as prioritizing action over explanation, that can facilitate learning and optimize performance (Wu et al., 2012). Game-assisted learning has become a crucial instructional approach, encouraging the exploration of new skills, boosting self-esteem, enhancing practice abilities, and positively influencing attitudes toward learning (Sarrell, 2014). Students engaged in game-assisted learning tend to have higher retention rates, and this approach stimulates chemical changes in the brain that facilitate memory storage, thereby improving overall learning outcomes (Jovanovic et al., 2008). An effective instructional game should, during periods of repetition, stimulate favorable

behaviors in students; this can be accomplished by promoting certain emotional and cognitive responses to interactions with and feedback from the game (Sailer & Homner, 2019). By increasing student motivation and engagement, game-assisted learning has become a widely adopted instructional method, drawing significant attention from researchers (Smiderle et al., 2020, (Li et al., 2024). Effective game-assisted learning should incorporate games that enhance learning, exist within environments grounded in influential learning theories, foster interaction between the player and the game, and provide fun, motivating opportunities to learn through mistakes (Li et al., 2024). In recent years, leading educational publishing companies have developed many gamified intervention options, such as Reflex Math.

Reflex Math

Reflex Math is a gamified computer-assisted learning tool called "the most effective math fluency solution" (Explore Learning, 2024a, para. 1). EReflex Math is an Explore Learning (2024a) online digital intervention program focusing on developing math fact fluency. This study's intervention uses the Cover, Copy, and Compare (CCC) procedure. The original intent of CCC was to help improve spelling accuracy, but Skinner et al. (1989) then used it to address recalling basic math facts. The program covers the whole process of fact mastery, from unknown facts to automaticity. It also differentiates instruction and adapts practice to each student's current ability and needs while using the program. The program is fun for students and creates a motivational environment, encouraging frequent use and reinforcing the link between effort and success in mathematics. Reports are intuitive and insightful, allowing educators to track fluency gains and system usage (Cholmsky, 2011).

Reflex Math covers the entire process of math fact mastery, including: a) systematic introduction of small sets of new facts, using appropriate strategies; b) development of the

student's preliminary ability to recall these new facts from memory; c) progression to timed retrieval once the student has demonstrated readiness; and d) automatization through game-based practice, in which facts can be recalled while the student's working memory is increasingly loaded with game-based tasks (Cholmsky, 2011). Students can work on their mathematics fact fluency (e.g. addition, subtraction, multiplication, and division) (Explore Learning, 2024b).

When students log into a session on Reflex Math, they are introduced to a small set of facts first. Then, the program provides opportunities for students to become proficient in recalling their newly learned facts. Reflex Math then introduces a timer and ends each session with game-based practice (Cholmsky, 2011). Students develop automaticity when facts are introduced and learned in small groups. According to Logan and Klapp (1991), students can achieve automaticity quickly when there is only a tiny amount of material to learn. Even with a large volume of material, individual components can be automated quickly through focused, independent practice. The Reflex Math gamified computer-assisted learning tool operates on the concept that achieving automaticity in math facts frees up cognitive resources, enabling students to tackle more complex math tasks (Sarrell, 2014). Willingham (2004) emphasizes that extensive practice, or overlearning, is crucial for solidifying memorized facts. Reflex Math aims to boost processing speed, enabling students to recall math facts effortlessly and without conscious effort.

Summary

This literature review highlighted the critical factors that shape current math education practices, particularly in light of the disruptions caused by the COVID-19 pandemic. By examining CLT, mathematics fact fluency strategies, and RTI frameworks, alongside the evolving role of EdTech and the impact of Common Core Standards, this study underscores the importance of adapting instructional methods to support diverse learner needs. Incorporating

gamification through platforms like Reflex Math offers promising avenues for addressing learning loss and enhancing student engagement. Chapter 3 describes the research technique and procedures used to conduct this study. It also discusses the type of research, data collection, and analysis.

Chapter 3: Methodology

Introduction

The purpose of this quantitative quasi-experimental study was to examine the relationship between the implementation of the Reflex Math program and third-grade students' mathematics achievement, as measured by Pennsylvania State Standardized Assessment (PSSA) Mathematics scores. This study specifically addresses the potential role of Reflex Math in mitigating learning loss in foundational math skills resulting from disruptions to education during the COVID-19 pandemic. By focusing on the 2022–2023 academic year, the research aims to explore whether the program serves as an effective intervention in improving addition and subtraction fact fluency, a critical skill area impacted by pandemic-related learning interruptions. In this study, Reflex Math was implemented as a Tier 1 intervention under the Response to Intervention Model (RTI) at the Seadog School over the 2022-2023 school year to provide support to all third-grade students. This chapter describes the research design, research questions, and their corresponding hypotheses. Further, it provides an overview of the participants, setting, instruments, and procedures used to collect and analyze the data.

Research Questions

RQ1. Does fact fluency for addition and subtraction significantly improve performance scores for third-grade students who use Reflex Math over the 2022-2023 school year?

$H1_0$. There is no statistically significant improvement in addition and subtraction fact fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

$H1_1$. There is a statistically significant improvement in addition and subtraction fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

RQ2. Is there a correlation between students' fact fluency in addition and subtraction and their PSSA scores?

$H2_0$. There is no correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

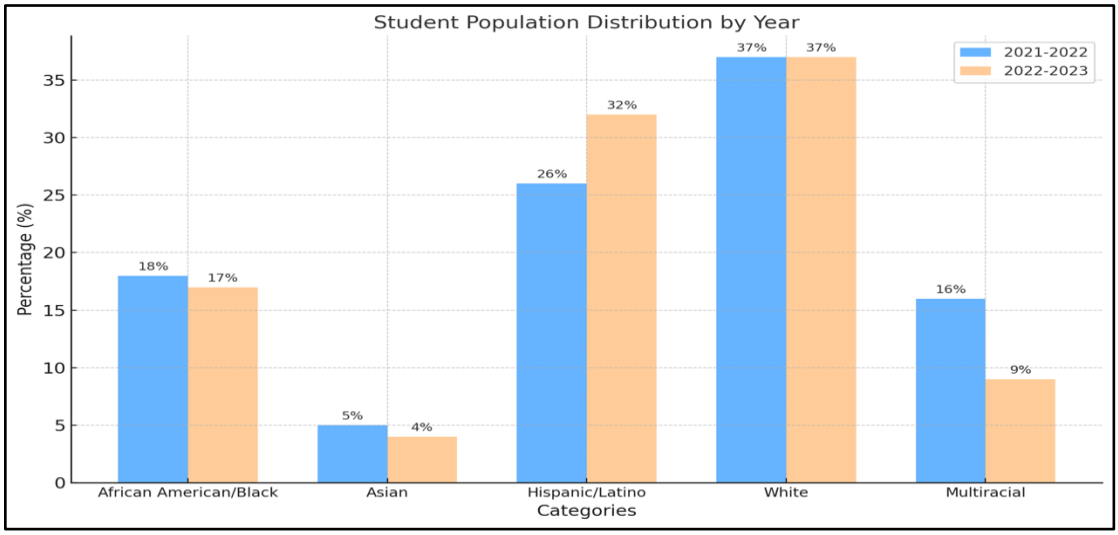
$H2_1$. There is a positive correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

Research Setting/Context

This study was conducted at Seadog School, which is part of an urban charter school district in eastern Pennsylvania and serves students in kindergarten through grade 12. The school district served 830 students enrolled in the 2021-2022 and 2022-2023 school years and includes a diverse student body at Seadog School (see Figure 3).

Figure 3

Student Population Distribution by Year



More specifically, White students accounted for 37% of the population in both years. The population of Hispanic/Latino students increased from 26% in 2021-2022 to 32% in 2022-2023, reflecting a notable demographic shift. Conversely, the proportion of Multiracial students decreased from 16% to 9% over the same period. African American/Black and Asian students experienced slight changes, with African American/Black students decreasing from 18% to 17% and Asian students decreasing from 5% to 4%, respectively. The Seadog School admits students from across the region, with over 60% of the student population qualifying for free or reduced-price meals under federal income eligibility guidelines or meeting other criteria for financial hardship (Universal Service Administrative Company, 2023). In response to reduced PSSA Mathematics achievement scores during the 2018-2019 academic year and in light of the suspended administration of the PSSA in 2019-2020 in response to the COVID-19 pandemic, leaders at Seadog School adopted Reflex Math as a universal intervention across all classrooms and grades from third grade to eighth grade through the 2022-2023 academic year.

Research Methodology and Design

To address the research questions effectively, the researcher used a quasi-experimental design, relying on secondary data sources, including Reflex Math fluency and usage reports and PSSA Mathematics scores from the 2021-2022 and 2022–2023 academic years. A quasi-experimental design was appropriate for this study because it allowed the researcher to examine the impact of the Reflex Math program on student achievement, as measured by PSSA Mathematics scores, without requiring random assignment (Chiang et al., 2015). Given the nature of the research setting, which included students who were already using Reflex Math, the manipulation of the independent variable (use of the Reflex Math program) occurred naturally within the existing structure (see Table 1).

Table 1

List of Dependent and Independent Variables

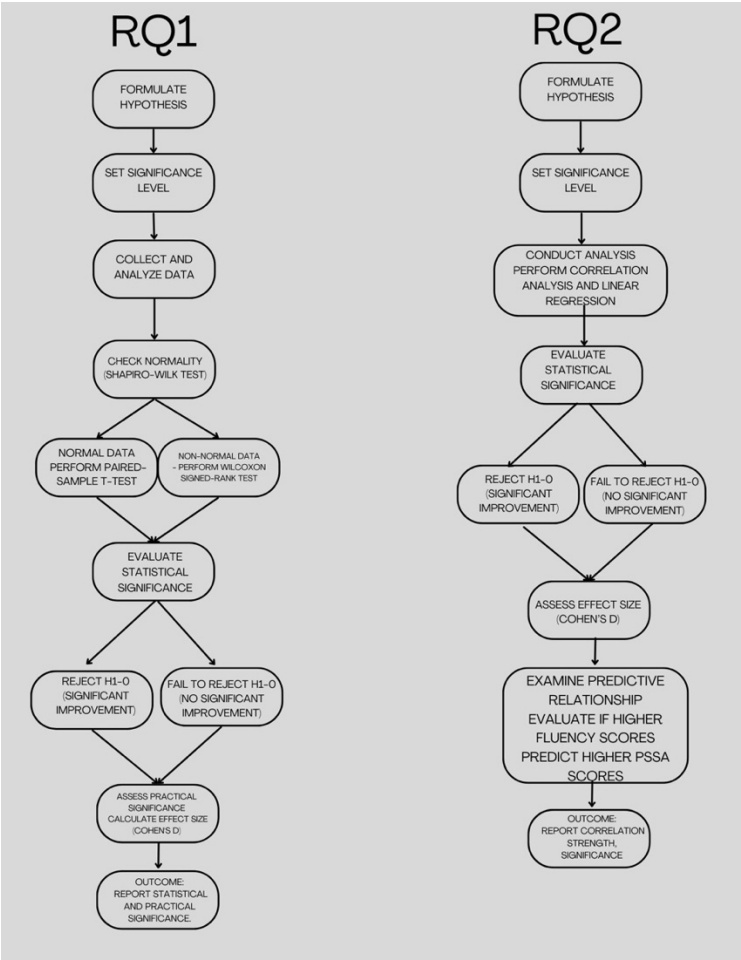
Dependent Variables (DV) Student Fact Fluency (Addition and Subtraction)	Current Fluency (%) This reflects the percentage of correct responses during math fluency exercises, providing a quantitative measure of students' fact fluency at the time of the study.	Math PSSA Scaled Score 2022 and 2023 This variable represents students' performance on the Pennsylvania System of School Assessment (PSSA) for math in the 2022 and 2023 testing years, offering a standardized measure of their overall math achievement.

Independent Variables (IV) Use of Reflex Math	Total Usage Days This variable tracks the total number of days each student engaged with Reflex Math throughout the study period.	Weekly Usage (Days per week) This measures the frequency of Reflex Math usage on a weekly basis, reflecting how often students interacted with the program during the study	Green Light Usage This indicator tracks how often the "green light" feature of Reflex Math was activated, which occurs when a student answers a certain number of math facts correctly in a session, signaling progress and mastery

Random assignment was not feasible in this context, as students were not placed into randomized treatment groups (Chiang et al., 2015). Instead, a quasi-experimental design allows the researcher to compare achievement outcomes between groups that either used Reflex Math or were exposed to other interventions or traditional methods (see Figure 4). This design allows for the investigation of causal relationships in real-world educational settings, making it ideal for evaluating the effectiveness of Reflex Math in addressing COVID-19-related learning loss and improving math fluency. The researcher used convenience sampling to assess the effectiveness of the Reflex Math program in improving mathematics achievement. The study uses data from accessible third-grade students, ensuring relevance to the program's real-world application. Although this method limits generalizability, it is suitable for assessing program impact within the local context, making it practical and time-efficient (Stratton, 2021).

Figure 4

Methodological Process



Data Analysis

The purpose of this quantitative quasi-experimental study was to examine the influence of Reflex Math on third graders' PSSA Mathematics achievement scores at Seadog School. There were two research guiding questions included in the study:

RQ1. Does fact fluency for addition and subtraction significantly improve performance scores for third-grade students who use Reflex Math over the 2022-2023 school year?

$H1_0$. There is no statistically significant improvement in addition and subtraction fact fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

$H1_1$. There is a statistically significant improvement in addition and subtraction fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

RQ2. Is there a correlation between students' fact fluency in addition and subtraction and their PSSA scores?

$H2_0$. There is no correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

$H2_1$. There is a positive correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

To answer RQ1, a two-paired sampled upper tail *t*-test was conducted to analyze the differences between the starting percentage of fact fluency and the end percentage of fact fluency. To address RQ2, linear regression and correlation analysis were conducted to ascertain the correlation between fact fluency and PSSA performance. In addition, linear regression allowed for the generation of variable significance with PSSA Mathematics performance score as the dependent variable.

RQ1 Data Analysis

The five-step test for hypothesis testing was used to evaluate the effectiveness of Reflex Math in improving addition and subtraction fact fluency for third-grade students. First, the null hypothesis ($H1_0$) stated that no significant improvement would occur, while the alternative hypothesis ($H1_1$) posited a significant improvement. The significance level (α) was set at .05. Data collected from pre- and post-intervention fluency tests were analyzed using a paired-sample *t*-test. The assumptions of normality were checked using the Shapiro-Wilk test. For non-normal data, a Wilcoxon signed-rank test was applied. Statistical significance was determined by the *p*-

value (.05), and effect size (Cohen's *d*) was calculated to assess the practical significance of the results.

RQ2 Data Analysis

To address RQ2, the relationship between students' fact fluency and their PSSA Mathematics performance was analyzed using linear regression, and correlation analysis was conducted to ascertain the correlation between fact fluency and PSSA Mathematics performance. Linear regression analysis was conducted to evaluate the relationship between students' fact fluency and their performance on the PSSA. The null hypothesis ($H2_0$) stated that no positive correlation existed between the two variables, while the alternative hypothesis ($H2_1$) posited a positive correlation. The significance level (α) was set at .05. The decision to reject or fail to reject the null hypothesis was based on the *p*-value, and the effect size was interpreted using Cohen's guidelines. This analysis examined whether higher fact fluency scores were associated with higher PSSA Mathematics scores, offering insights into the predictive relationship between these variables.

Ethical Assurances

The Gwynedd Mercy University Institutional Review Board (IRB) approved this research study under an exempt status on May 10, 2024 (see Appendix A). Permission to conduct the study was obtained from the Chief Executive Officer of the Seadog School. After permission was granted, the principal of the Seadog School shared the de-identified data for third-grade students. The data included the baseline fluency scores, and end-of-year fluency scores obtained from Reflex Math. The principal also de-identified and shared the PSSA Mathematics results for Spring 2022 and Spring 2023. The data included the students' scaled scores. All data were stored

on a password-protected laptop, and the committee chair and the researcher were the only individuals with access to view the data; it was not shared with anyone.

The researcher then combined the data sets (e.g., PSSA Mathematics scores and Reflex Math fluency scores) onto a Microsoft Excel spreadsheet. Microsoft Excel is a spreadsheet application that enables users to format, organize, and calculate data within a spreadsheet (Coursera Staff, 2023). The researcher then imported the spreadsheet into Jeffery's Amazing Statistics Program (JASP) JASP, a free and open-source statistical software (Wu et al., 2020).

Summary

This quantitative quasi-experimental study aimed to assess the effectiveness of the Reflex Math program in enhancing third-grade students' PSSA Mathematics achievement, particularly considering learning disruptions caused by the COVID-19 pandemic. By focusing on the 2022-2023 academic year, the research investigated to what extent the implementation of Reflex Math improved addition and subtraction fact fluency and whether a correlation existed between this fluency and performance on the PSSA.

The study employed a quasi-experimental design, utilizing secondary data from Reflex Math fluency reports and PSSA scores, allowing for a natural examination of the program's impact without random assignment. The research setting reflected a diverse student population and included a significant proportion qualifying for free or reduced-price meals.

The analysis involved hypothesis testing to evaluate the improvement in fact fluency and to what extent fluency scores correlated with performance on the PSSA Mathematics test, using appropriate statistical methods to ensure robust results. Ethical considerations were addressed, thus ensuring confidentiality and compliance with institutional guidelines. Chapter 4 illustrates the results of the study, including statistical results.

Chapter 4 Results

Introduction

This chapter examines the results of the study by looking at the relationship between third-grade students' use of Reflex Math and their ability to add and subtract. The researcher also investigated the possible relationship between fact fluency and their performance on the Pennsylvania System of School Assessment (PSSA) Mathematics test. The chapter is structured into sections that align with the study's main objectives. The chapter begins with the evaluation of students' advancement in fluency during the academic year 2021-2022, as assessed by Reflex Math. The second part assesses whether this advancement correlates with enhanced performance on the PSSA. The researcher analyzes the relationship between students' fluency and their PSSA scores, evaluating the hypothesis of a positive correlation. Descriptive and inferential statistical techniques are used to analyze the data, including main trends, standard deviation, and correlation coefficients. Tables and graphs are incorporated to illustrate results and provide a visual representation of the results. The findings in this chapter serve as the foundation for the discussion in Chapter 5, where the findings are positioned relative to the current research.

Descriptive Overview of the Data Set

The study was conducted to answer two research questions. The first research guiding question focuses on whether fact fluency for addition and subtraction significantly improves performance scores for third-grade students who use Reflex Math over the 2022-2023 school year. The second question is focused on identifying if there is a correlation between students' fact fluency in addition and subtraction and their PSSA scores.

The data set used to answer the questions for this study comprised of 55 third-grade students who attended Seadog School during the 2022-2023 academic year. All participants met

specific inclusion criteria to ensure the consistency and validity of the data. To be included, students had to be continually enrolled at Seadog School throughout the school year, have participated in the Spring 2022 Pennsylvania System of School Assessment (PSSA) Mathematics exam, and completed the Spring 2023 PSSA Mathematics exam. Additionally, all students had access to Reflex Math as part of their instructional programming during the 2022-2023 school year. There were no exclusions from the data set, as all students who met the outlined criteria were included in the analysis.

The Reflex Math fluency data was analyzed to assess changes in third-grade students' fact fluency over the course of the 2022-2023 school year, and initial and present fluency percentages were examined. Table 2 summarizes the key descriptive statistics.

Table 2

Summary Statistics of Students' Starting Fluency % and Current Fluency %

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Current Fluency (%)	55	0	55	4.132	100.000	54.408	29.669
Starting Fluency (%)	55	0	55	0.000	90.083	20.935	22.903

The mean starting fluency percentage was 20.93, with a standard deviation of 22.90, indicating a wide range of initial fluency levels among the students. The minimum starting fluency was 0%, and the maximum was 90.083%. By the end of the 2022-2023 school year, the

mean fluency increased to 54.40%, with a standard deviation of 29.66. The minimum current fluency was 4.13%, and the maximum reached 100%.

The PSSA Mathematics scores and Reflex Math usage data provide insights into students' performance and engagement with the intervention (see Table 3).

Table 3

Summary of Descriptive Statistics

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Scaled Score 23	55	0	55	780.000	1114.000	940.818	79.359
Total Usage (days)	55	0	55	9.000	101.000	45.873	26.421
Weekly Usage (days/wk)	55	0	55	0.000	4.000	.927	.940
Green Light Usage (%)	55	0	55	0.000	91.089	29.904	23.581
Current Fluency (%)	55	0	55	4.132	100.000	54.408	29.669
Scale Score 22	55	0	55	798.000	1172.000	948.400	93.942

The 2023 PSSA Mathematics scaled scores had a mean of 940.81 with a standard deviation of 79.35, ranging from a minimum of 780 to a maximum of 1114. The 2022 PSSA Mathematics scaled scores were slightly higher on average, with a mean of 948.40 and a

standard deviation of 93.94, ranging from 798 to 1172. When analyzing the amount of Reflex Math usage, the total usage days varied widely, with a mean of 45.87 days (about one and a half months), and a standard deviation of 26.42. Weekly usage averaged about 3.18 hours per week, with a maximum of four days per week. Green Light Usage, representing the percentage of sessions where students demonstrated proficiency, averaged 29.904%, with a standard deviation of 23.581%.

The descriptive statistics indicate significant trends in fact fluency growth, PSSA Mathematics achievement, and Reflex Math utilization. Students demonstrated substantial improvement in fluency during the academic year, with the average fluency rising from 20.935% to 54.408%. The extensive score range (initial fluency: 0%–90.083%; current fluency: 4.132%–100%) shows a great deal of variation in students' starting proficiency and growth. PSSA Mathematics scores exhibited fluctuation, with average scaled scores of 940.82 in 2023 and 948.40 in 2022, indicating a minor decrease in performance. The substantial standard deviations for both years underscore disparities in student attainment levels.

Reflex Math usage data indicates variety in involvement with students utilizing the program for an average of 45.873 days (about one and a half months) throughout the academic year, while usage spans from nine to 101 days (about three and a half months). Weekly usage was less than one day per week (.927 days), and students attained Green Light competency in fewer than one-third of sessions on average (29.904%). The differences in participation could have an impact on the variation in PSSA outcomes and fluency gains. Initial trends suggested that better PSSA performance might be associated with greater use of Reflex Math and improved fluency, which calls for further research employing statistical analysis.

Validity and Reliability of Data

The researcher conducted a power analysis to ensure that there was an appropriate number of participants for the upper tail *t*-test to generate enough data points. The results indicated that the 55 participants used in the study would be enough with a medium effect size convention of .4 and a power of .8. Figure 5 presents a power analysis, showing the relationship between statistical power (1−β) and the required sample size. As the desired power increases, the sample size grows, particularly for moderate effect sizes (d = .4). This analysis is based on a one-tailed *t*-test with a significance level of .05 and underscores the importance of adequate sample size to achieve sufficient power, typically set at .8 (80%).

Figure 5

Power Analysis

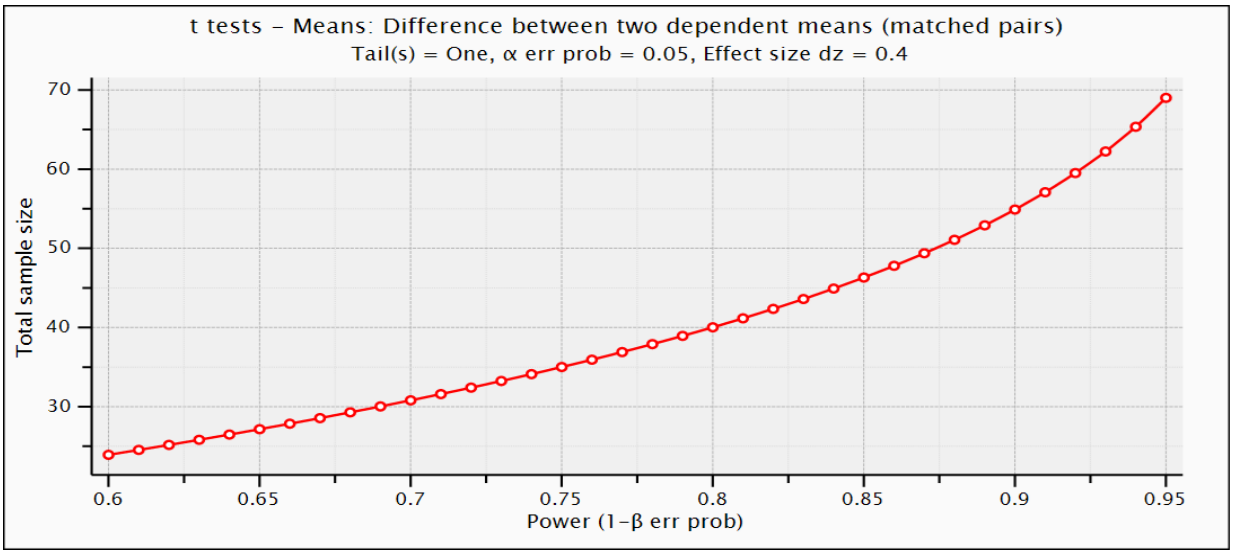
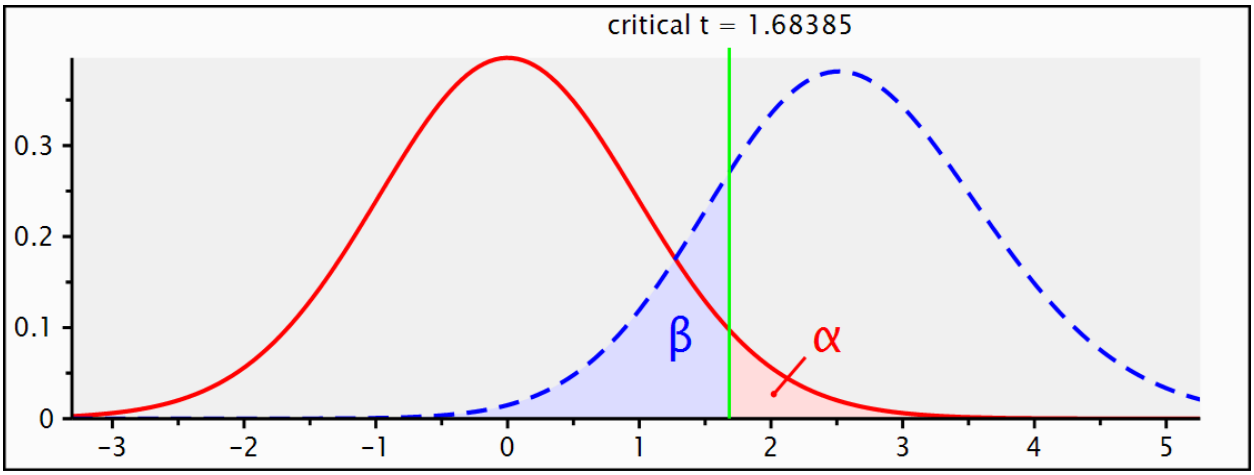


Figure 6 shows the correlation among Type I error (α), Type II error (β), and statistical power about hypothesis testing to address RQ1. The red curve denotes the null hypothesis (H_0), whereas the blue dashed curve signifies the alternative hypothesis (H_1). The critical t-value (t = 1.68385) acts as the benchmark for null hypothesis rejection, with the area under the red curve to the right of this value indicating Type I error (α)—the likelihood of rejecting H_0 when it is valid.

In contrast, Type II error (β), or the probability of not rejecting H_0 when H_1 is valid, is represented by the shaded area beneath the blue curve to the left of the crucial value. The area beneath the blue curve to the right of the critical value represents statistical power (1 - β), or the probability of correctly rejecting H_0 when H_1 is valid. In order to demonstrate reliable and accurate results regarding the effectiveness of Reflex Math in improving third-grade students' addition and subtraction fluency, Figure 6 emphasizes the need to equilibrate α and β.

Figure 6

Critical Value and Error Regions



RQ1 Results

To answer RQ1, does fact fluency for addition and subtraction significantly improve performance scores for third-grade students who use Reflex Math over the 2022-2023 school year, a paired-sample *t*-test was conducted to determine whether the use of Reflex Math over one school year resulted in a significant improvement in students' addition and subtraction fact fluency. The analysis revealed a mean difference of 33.47 between pre- and post-intervention scores, with a 95% confidence interval lower bound of 28.493. The *t*-statistic (11.247) exceeded the critical value (1.674), and the *p*-value was less than .0001, which is significantly lower than the alpha level of .05 (see Table 4, Figure 7). These results indicate that the improvement in

fluency was both statistically significant and meaningful. As such, the null hypothesis, which stated that there is no difference in means, was rejected in favor of the alternative hypothesis, confirming that Reflex Math had a statistically significant positive impact on students' fact fluency over the course of the school year based on the statistically significant increase in the final score.

Table 4

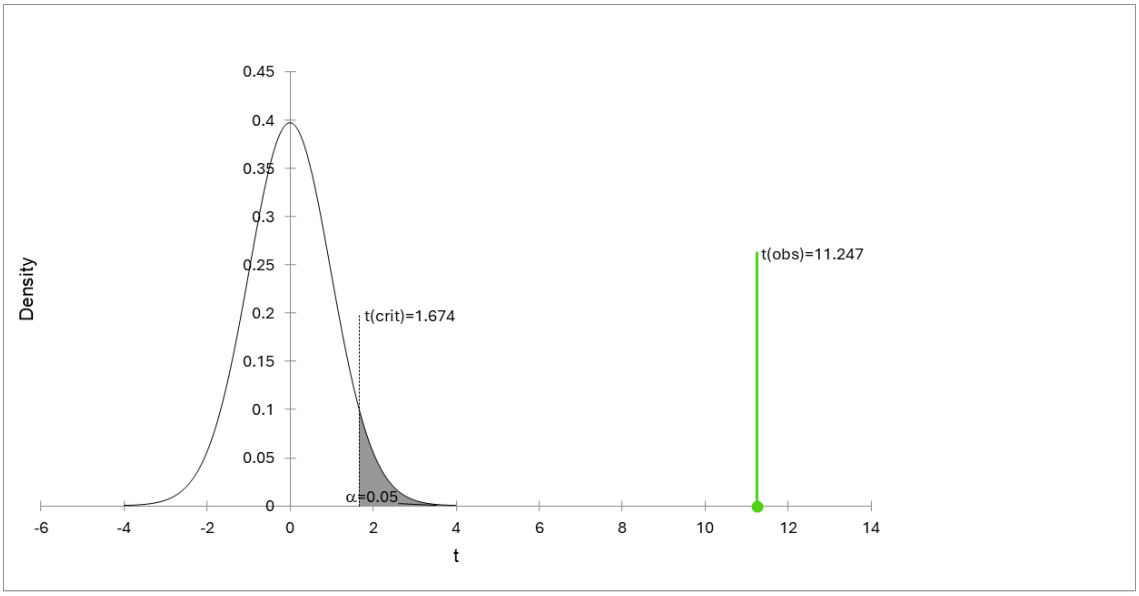
t-Test for Two Paired Samples: Starting Fluency and Current Fluency

95% confidence interval on the difference between the means: [28.493, +Inf [	
Difference	33.474
t (Observed value)	11.247
t (Critical value)	1.674
DF	54
p-value (one-tailed)	**< .0001**
alpha	.05

The number of degrees of freedom is approximated by the Welch-Satterthwaite formula.

Figure 7

Starting Fluency and Current Fluency t-Test

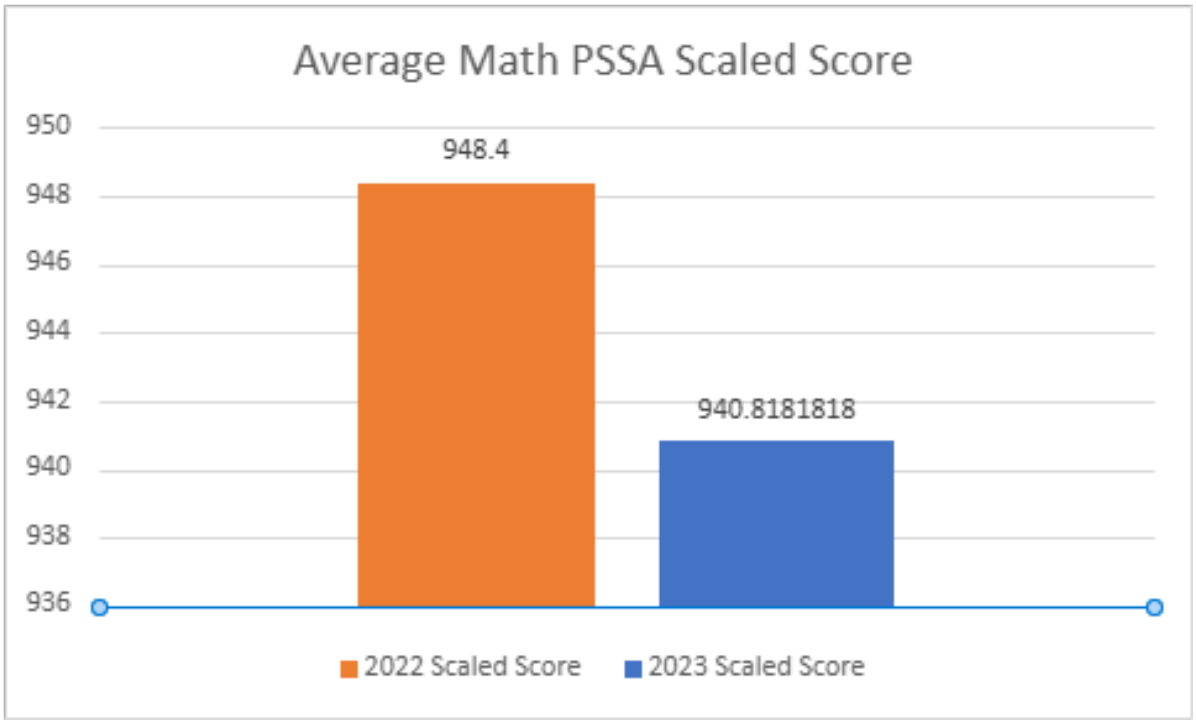


RQ2 Results

To investigate RQ2, is there a correlation between students' fact fluency in addition and subtraction and their PSSA scores, the researcher explored the relationship between the average 2022 PSSA scaled score and the average 2023 PSSA scaled score first (see Figure 8). The research found a slight decrease in the average PSSA scaled score, dropping from 948 in 2022 to 940 in 2023, which calls for further investigation into possible contributing factors.

Figure 8

Average Math PSSA Scaled Score



To explore this, linear regression and correlation analysis were used to examine the association between students' fact fluency and their PSSA performance. The correlation analysis revealed weak and inconsistent relationships. The correlation between the current fluency percentage and the 2022 PSSA scaled score was $r = .099$ while for the 2023 PSSA scaled score, it was $r = -0.129$ (see Table 5).

Table 5

Correlation Matrix

	Total Usage (days)	Weekly Usage (days/wk)	Green Light Usage (%)	Current Fluency (%)	Scale Score 22	Scaled Score 23

Total Usage (days)	1	.670	.257	.603	.032	-0.274
Weekly Usage (days/wk)	.670	1	.595	.479	-0.055	-0.062
Green Light Usage (%)	.257	.595	1	.393	.054	.114
Current Fluency (%)	.603	.479	.393	1	.099	-0.129
Scale Score 22	.032	-0.055	.054	.099	1	.205
Scaled Score 23	-0.274	-0.062	.114	-0.129	.205	1

These values indicate weak and non-significant associations. Usage metrics, such as Total Usage (days), demonstrated negligible correlation with the 2022 scaled score ($r = .032$) and a weak negative correlation with the 2023 scaled score ($r = -0.274$). Other indicators, such as weekly usage (days/week) and Green Light Usage (%), displayed similarly weak correlations, ranging from $r = -0.062$ to $r = .114$. These results suggest that neither fact fluency nor Reflex Math usage metrics are strongly linked to standardized test outcomes. The regression analysis provided additional insights into the predictors of the 2023 Scaled Score (see Table 6).

Table 6

Linear Regression of Scaled Score 23

Number of variables	Variables	MSE	R^2	Adjusted R^2
3	Total Usage (days) / Weekly Usage (days/wk) / Scale Score 22	5628.541	**0.156**	0.106

Model parameters (Scaled Score 23):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)	p-values signification codes
Intercept	796.195	113.366	7.023	<**0.0001**	568.603	1023.787	***
Total Usage (days)	-1.357	0.391	-3.472	**0.001**	-2.141	-0.572	**
Weekly Usage (days/wk)	21.449	8.780	2.443	**0.018**	3.823	39.075	*
Green Light Usage (%)	0.000	0.000					
Current Fluency (%)	0.000	0.000					
Scale Score 22	0.197	0.117	1.681	0.099	-0.038	0.433	.

*Signification codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 <. < 0.1 < ° < 1*

The model explained 15.6% of the variation in scores (R^2 = .156, Adjusted R^2 = .106) and was statistically significant. Significant predictors included Total Usage (days), which showed a negative relationship (β = −1.357, p = .001), and Weekly Usage (days/week), which demonstrated a positive relationship (β = 21.449, p = .018). These results suggest that consistent weekly usage had a positive impact on test scores, whereas excessive total usage may negatively affect outcomes. Scaled Score 22 was marginally significant (β = .197, p = .099), indicating that prior PSSA performance has some predictive value. Of note, Current Fluency (%) and Green Light Usage (%) were not significant predictors, further highlighting the limited direct influence of fluency on PSSA performance.

It is clear from analyzing the data that consistent weekly involvement, or quality of usage, had a greater influence than overall usage. PSSA scores and fact fluency have weak and statistically negligible correlations, indicating that fact fluency is not a reliable indicator of performance on standardized tests. Rather, other elements like past academic achievement and regular use of learning resources are more important.

In summary, the null hypothesis ($H2_0$), which holds that fact fluency and PSSA scores do not positively correlate, is supported by both the regression and correlation analyses. Despite being a crucial ability, these findings imply that fact fluency does not always translate into better results on the PSSA, which measures standardized tests. The findings highlight how important it is to look at more variables in order to comprehend the elements affecting PSSA performance.

Summary

This chapter investigated the correlation between third-grade students' use of Reflex Math and their proficiency in addition and subtraction, as well as the possible association between fact fluency and their performance on the PSSA. The data gathered from 55 students at Seadog School during the 2022-2023 academic year were analyzed using descriptive and inferential statistical techniques. The results showed significant trends in fact fluency growth, PSSA Mathematics achievement, and Reflex Math utilization. Students demonstrated substantial improvement in fluency during the academic year, with an average fluency rising from 20.935% to 54.408%. However, the study also discovered notable differences in participation with students using the program for an average of 45.87 days (about one and a half months with a minimum of nine days and a maximum of 101 days) throughout the academic year. The results suggest that increased Reflex Math utilization and enhanced fluency improvement may correlate with superior PSSA Mathematics performance.

The researcher conducted a power analysis to ensure the appropriate number of participants for the upper tail *t*-test to generate enough data points. The results indicated that the 55 participants used in the study were enough with a medium effect size convention of .40 and a power of .80. The study found a significant improvement in students' addition and subtraction fact fluency over one school year, with a 95% confidence interval lower bound of 28.493. The

null hypothesis was rejected in favor of the alternative hypothesis, confirming that Reflex Math had a significant positive impact on students' fluency over the course of the school year. The correlation analysis revealed weak and inconsistent relationships between students' fact fluency and their PSSA performance for the 2022-2023 school year. The best model for the selected selection category was found to explain 15.6% of the variation in scores and was statistically significant. The results suggest that the quality of usage (consistent weekly engagement) is more impactful than the total amount of usage.

Chapter 5 further examines the implications of these results and explores the relationship between Reflex Math usage and third-grade students' academic performance. By examining the quality of usage versus the quantity, the researcher aims to understand how consistent engagement with the program may lead to improved fact fluency and potentially higher standardized test scores. Additionally, the researcher will discuss potential recommendations for educators based on these results to optimize student outcomes in mathematics education.

Chapter 5 Discussion, Conclusions, and Recommendations

Summary of Study

This chapter provides a comprehensive discussion of the study results, interprets their significance in relation to how this study contributes to the field of education, and provides actionable insights for improving student outcomes by situating the results within the context of existing research and educational practices. This study investigated the relationship between fact fluency in addition and subtraction and third-grade students' performance on the Pennsylvania System of School Assessment (PSSA) Mathematics test over the 2022-2023 school year. It specifically examined whether third-grade students' addition and subtraction fluency improved by using Reflex Math and to what extent addition and subtraction fact fluency and PSSA Mathematics scores are positively correlated. Determining how digital learning resources can improve academic achievement and further educational objectives requires addressing these issues. The results and how they relate to the aim of the study are summarized at the beginning of this chapter, and the resulting effects are discussed in detail. The researcher also discusses the limitations of the study, identifying areas requiring more investigation through future research while also considering the study's broader relevance.

Discussion

The analysis focused on addressing two primary research questions:

RQ1. Does fact fluency for addition and subtraction significantly improve performance scores for third-grade students who use Reflex Math over the 2022-2023 school year?

$H1_0$. There is no statistically significant improvement in addition and subtraction fact fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

$H1_1$. There is a statistically significant improvement in addition and subtraction fluency for third-grade students who use Reflex Math over the 2022-2023 school year.

RQ2. Is there a correlation between students' fact fluency in addition and subtraction and their PSSA scores?

$H2_0$. There is no correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

$H2_1$. There is a positive correlation between third-grade students' fact fluency in addition and subtraction and their performance on the PSSA.

RQ1

The five-step hypothesis test was used to evaluate RQ1, which measured the effectiveness of Reflex Math in improving addition and subtraction fact fluency for third-grade students. First, the null hypothesis ($H1_0$) stated that no significant improvement would occur, while the alternative hypothesis ($H1_1$) posited a significant improvement. The significance level (α) was set at .05. Data collected from pre- and post-intervention fluency tests were analyzed using a paired-sample *t*-test. The assumptions of normality were checked using the Shapiro-Wilk test. The data analysis revealed that the null hypothesis was rejected, and the alternative hypothesis was accepted, indicating that addition and subtraction fact fluency was statistically significant and that Reflex Math positively impacted students over the course of the 2022-2023 school year.

These results are consistent with research demonstrating the benefits of using gamified computer-assisted learning tools (e.g., Reflex Math) that respond to students' performance and progress (Riccomini et al., 2017; Wu et al., 2012) as a Tier 1 intervention under the Response to

Intervention (RTI) model to increase addition and subtraction fluency in elementary children (Searle, 2010). More specifically, Riccomini et al. (2017) found that basic math facts are more likely to be taught effectively when instructional methods are customized to the specific requirements and ability level of the student. Similarly, Li et al. (2024) and Jovanovic et al. (2008) found comparable increases in mathematical fluency (i.e., addition, subtraction, multiplication, and division) by means of interactive, technology-based learning environments. Searle (2010) found that using RTI is an effective approach that provides targeted intervention to students with challenges. This study's results highlight the success of gamified, computer-assisted learning tools like Reflex Math in improving mathematical fluency, especially when combined with the RTI paradigm to deliver personalized, proactive, and adaptive interventions for elementary pupils, which corroborates research by Wang et al. (2024).

RQ2

To address RQ2, the five-step hypothesis test was used to evaluate the relationship between students' fact fluency and their PSSA Mathematics scores. First, the null hypothesis ($H2_0$) stated that no positive correlation exists between the two variables, while the alternative hypothesis ($H2_1$) posited a positive correlation. The significance level (α) was set at .05. Data collected on the students' fact fluency and their PSSA Mathematics performance were analyzed using linear regression and correlation analysis to determine the correlation between fact fluency and PSSA Mathematics performance. The data analysis revealed that the alternative hypothesis was rejected, and the null hypothesis was accepted, indicating that neither fact fluency nor Reflex Math usage indicated a positive correlation with standardized test scores.

While fact fluency is an important factor for improved performance on assessments like the PSSA Mathematics, it is also influenced by other crucial elements, including conceptual

understanding, problem-solving skills, and test-taking strategies, all of which are comprehensively assessed by the PSSA (Commonwealth of PA, n.d.-a). This suggests that while foundational math skills are necessary, their impact on standardized testing may be moderated by these additional factors. This could explain the minimal relationship demonstrated between consistent Reflex Math usage and PSSA Mathematics results. According to research, the quality and context of learning activities are equally important as the frequency with which they are practiced (Sawchuk, 2023). For example, while practice can be brief, regular and repeated opportunities for students to practice over time are beneficial (Sawchuk, 2023). Additionally, students do not benefit from prolonged drill exercises, as this can create a misconception that mathematical computation requires no thinking (Bielsker et al., 2001).

Considering the broader context of the COVID-19 pandemic is crucial for understanding the potential factors influencing student performance. These third-grade students began their education as kindergarteners during the peak of the pandemic, with disruptions such as extended periods of virtual learning, limited access to in-person instruction, and different amounts of parental support. According to research, the pandemic had a substantial impact on educational systems, leading to severe learning losses, particularly in mathematics (Morton et al., 2022). These setbacks are critical and have long-term consequences for children's academic development. Such contextual factors likely influenced students' foundational learning experiences and their performance on assessments, including the PSSA. These issues, worsened by the digital divide, particularly in areas with low technology access, the pandemic has brought more attention to pre-existing educational inequalities. (Kumi-Yeboah et al., 2023, Olawunmi & Osakwe, 2021), which greatly impacted students in urban areas of eastern Pennsylvania, widened existing imbalances and resulted in significant learning gaps (A'yun et al., 2022). Kuhfeld et al.

(2020) found that students preserved only 37% to 50% of their average learning gains in mathematics during the 2019-2020 school closures, highlighting the considerable impact of learning loss on academic attainment.

The COVID-19 pandemic has had a lasting impact on students' foundational learning, particularly in mathematics, which is evident in the challenges faced by students who began their education during this period. Despite the potential benefits of online learning, Students from disadvantaged backgrounds often face more significant challenges in accessing technology and online resources, leading to disparities in learning outcomes (Olawunmi & Osakwe, 2021).

The students included in this study started kindergarten during the 2020-2021 school year, which was the height of the COVID-19 pandemic. By the time they were in third grade, they were not fluent in addition and subtraction, which demonstrates some learning loss experienced during the COVID-19 pandemic. Although gamified computer-assisted learning tools (e.g., Reflex Math) are useful in assisting learning by promoting engagement, providing immediate feedback, and allowing for personalized practice, students' mathematics performance is dependent on their integration with strong instructional approaches that address broader difficulties (Zhang et al., 2022). The pandemic emphasized the need to include such tools in teaching practices and also to move beyond simple usage numbers to gain a more holistic understanding of their impact.

Implications

Mathematical fluency is not only essential for addressing the mathematics achievement gap but also aligns with principles of cognitive load theory, which emphasizes the importance of optimizing cognitive processes to enhance learning outcomes. According to Baker and Cuevas (2018), students who can automatically recall basic math facts free up cognitive resources for

higher-level reasoning, a concept central to cognitive load theory. Research highlights that developing automaticity in fundamental operations (addition, subtraction, multiplication, and division) by the end of third grade is critical, as students without this foundation are more likely to struggle with complex mathematical concepts requiring greater cognitive effort (Berrett & Carter, 2017; Parkhurst et al., 2010). Cognitive load theory further suggests that educators can improve instructional design by building on students' prior knowledge and mental frameworks (Saunders, 2020), enabling more effective knowledge construction and supporting the development of foundational skills necessary for future success in mathematics.

Although the impact of Reflex Math on third-grade students' performance on standardized tests (e.g., PSSA Mathematics) remains to be seen, using Reflex Math could improve students' automaticity in addition and subtraction, allowing students to apply that knowledge to multiplication and division fluency. In time, those students would be better positioned to experience success when introduced to mathematical concepts with increased cognitive demands. math concepts and strategies that they are learning in the classroom.

Moving forward, it is essential to continue exploring innovative approaches that combine evidence-based strategies with technology to close achievement gaps and foster deeper mathematical understanding. Ultimately, the integration of these various elements can help create more resilient and effective learning environments, ensuring that all students have the opportunity to succeed in mathematics, regardless of the challenges they face.

Limitations of the Study

Although this study has several strengths, it also includes some limitations. For example, the sample size ($N = 55$) is limited to a single school, which may not accurately represent the larger community, limiting the results' application to other educational contexts. Further, the

descriptive statistics of the sample were limited to the students' grade levels. Future research should identify students' date of birth, sex, and socioeconomic status, for example. In addition, data were collected only for two PSSA testing years (2022 and 2023), which may not represent variability in student performance over a longer period of time or across different grades; however, based on the statistical power of the sample, the results are still generalizable to the population at Seadog School.

Furthermore, the intervention period for the usage of Reflex was limited to one school year, which may limit the program's effectiveness and the capacity to analyze long-term effects on the students' learning. These aspects underscore the importance of exercising caution when interpreting the results, as well as the need for additional studies to investigate these results in a more diversified and extended context.

Additionally, the study did not control other variables that might influence student achievement, such as teacher instructional strategies, classroom environment, or parental involvement; however, based on the results, these variables can be included in future studies to determine if they do present any level of statistical significance or influence on students' achievement.

Another limitation of the study is the use of PSSA Mathematics scores, as the PSSA exams are designed to provide a broad measure of student achievement across the entire school year. The exam's content is general and may not specifically target skills like addition and subtraction fact fluency, which is the focus of Reflex Math. This could limit the ability to draw strong connections between the Reflex Math program and PSSA Mathematics scores.

While the use of Reflex Math had a significant impact, it is important to acknowledge that these other factors stated above may have also contributed to the positive results. Future studies should control these variables to isolate the specific effects of Reflex Math.

Recommendations for Future Practice

First, the statistically significant improvement in addition and subtraction fact fluency through the use of Reflex Math suggests that integrating gamified adaptive learning technologies into the classroom can effectively enhance students' foundational mathematical skills. The individualized practice and immediate feedback afforded by Reflex Math likely contributed to the students' observed gains, highlighting its potential as a valuable tool for addressing diverse student needs. Schools and districts should consider adopting such tools to supplement traditional instructional methods, particularly for students who struggle with math fluency as a Tier 1 intervention under the RTI model. When considering the results of this study, educators and policymakers should continue to prioritize fluency-building mathematics activities, recognizing that these skills may support students' confidence and efficiency in problem-solving, even if their direct impact on standardized assessments varies. Given the weak correlation observed, administrators should consider complementing fluency-building programs like Reflex Math with broader instructional strategies that target critical thinking, reasoning, and problem-solving skills, which are also essential for success on standardized tests.

Finally, policymakers should recognize the nuanced relationship between foundational skills and standardized assessment performance when planning curriculum and resource allocation. While investing in fluency programs is important, additional emphasis should be placed on comprehensive mathematics instruction that integrates conceptual understanding and application skills. By addressing these areas, stakeholders can better support student learning

outcomes and prepare students for success in both foundational and higher-order mathematical tasks.

Recommendations for Future Research

Future research should consider longitudinal studies that track third-grade students over multiple years or follow students as they progress through subsequent grades to assess the long-term impact of Reflex Math. While this study found significant improvements in addition and subtraction fact fluency, it did not evaluate whether these gains were sustained over time or outside of the classroom. A longitudinal study could address this gap, determining whether the benefits of fluency persist as students continue their academic journey. Additionally, the small sample size of 55 students in a single grade limits the generalizability of the findings. Replicating this study with a larger, more diverse sample across multiple grade levels would provide a more comprehensive understanding of how Reflex Math impacts student achievement and the broader factors influencing academic performance. Future research should explore other factors that may mediate or influence the connection between basic mathematics skills and performance on standardized assessments like the PSSA.

Conclusions

Throughout this study, my primary goal was to determine whether using Reflex Math throughout a school year could lead to statistically significant improvements in mathematics fact fluency and whether those purported gains correlated with standardized test outcomes. As an educator, I am often given instructional tools and professional development through the district, but rarely do I learn the reasons for using these tools and if the tools are even effective. Instructional time is valuable, so if I am taking the time to have students use a tool, it should be beneficial for the majority of students. Additionally, with the pressure on performance on

standardized test scores, I wanted to know if using Reflex Math had the potential to lead to improved performance on the PSSA Mathematics test. This study addresses this gap, contributing to the growing body of research on the role of educational technology in improving both foundational skills and broader academic achievement.

After completing the study, I learned a lot of essential information that helped me understand educational studies and the purpose of gamified learning tools like Reflex Math. I also learned how important it is to view gamified learning tools in the bigger picture of instructional pedagogy. It was clear that Reflex Math helped students remember facts better, but it did not have much of an effect on their ability to think mathematically in general. This highlights how important it is to teach students in a more complete way, targeting multiple skills at a time. Lastly, this experience has taught me how dynamic the research process can be, highlighting the importance of adaptability and openness to new challenges and ideas. This growth has not only reshaped my perspective on research but has also enhanced my ability to think critically about effectively applying teaching tools in meaningful ways.

In conclusion, this study explored the relationship between addition and subtraction fact fluency and third-grade students' performance on the PSSA Mathematics test, focusing on the potential impact of Reflex Math. The study found that Reflex Math impacted third-grade students' addition and subtraction fluency, which reinforces the benefits that gamified learning tools can provide for elementary school students. Although this study found statistically significant gains in students' mathematics fluency over time, it found a weak and unreliable link between using Reflex Math and performance on PSSA Mathematics test. While it is possible that Reflex Math might support students' mathematics fluency in addition and subtraction, there does not appear to be a direct impact on students' capacity to think mathematically and solve

problems in general. Of note, though, is the concept that more mathematically fluent students are better equipped to apply and increase cognitive load toward solving more complicated mathematical concepts. Additional research is crucial to investigate the factors influencing the relationship between basic math skills and performance on standardized assessments. This study emphasizes the essential need for an instructional method that combines conceptual comprehension with the practical application of fundamental mathematical concepts, ensuring students are prepared to succeed in challenging problem-solving situations throughout their educational careers.

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Appendices

Appendix A: IRB Approval

Subject: APPROVED EXEMPT/045-24-IRB/Luu, Linh Tuyet/Do Students Who Use the Reflex Mathematics Program Have Improved PSSA Mathematics Scores?
Dear Ms. Luu:
On behalf of the Gwynedd Mercy University Institutional Review Board, I am pleased to inform you that the Board has reviewed your research proposal and has determined that the proposal, as submitted, is **APPROVED EXEMPT.**

This approval is for a period of one year from the date of this letter and will require a formal submission for re-approval with the IRB along with a progress report should it extend beyond the one year timeline.

The IRB shall have authority to suspend or terminate approval of research that is not being conducted in accordance with the IRB's requirements or that has been associated with unexpected serious harm to subjects. Any suspension or termination of approval will be determined by the committee as a whole, shall include a statement of the reasons for the IRB's action and shall be reported promptly to the principal investigator and appropriate institutional officials. Should any changes need to be made to the protocol during the period of approval, you must submit a revised protocol using form IRB-007 to the IRB for approval before implementing the changes. Should any problems or adverse events occur during the research, these must be reported to the IRB in a written report in accordance with IRB guidelines.

For all "EXPEDITED" or "FULL" reviews, the principal investigator must inform the IRB in writing when the research project has been completed through the submission of a study completion form (IRB Form 011) with a summary of the research and records and copies of manuscripts or abstracts resulting from the approved research.

We appreciate your adherence to the standards designed to protect the rights of human subjects utilized in research studies and wish you luck in your proposed research. If you have any questions regarding the IRB's decision or any part of the IRB process through the completion of your study, please contact the IRB Administrator.

Sincerely,

Gail E. Christiansen.
IRB Coordinator
Gwynedd Mercy University
christiansen.g@gmercyu.edu

Appendix B: CITI Certifications

CITI PROGRAM

Completion Date 28-Aug-2022
Expiration Date 27-Aug-2025
Record ID 50970216

This is to certify that:

Linh Luu

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Social & Behavioral Research - Basic/Refresher
(Curriculum Group)
Social & Behavioral Research
(Course Learner Group)
1 - Basic Course
(Stage)

Under requirements set by:

Gwynedd Mercy University

CITI
Collaborative Institutional Training Initiative

101 NE 3rd Avenue, Suite 320
Fort Lauderdale, FL 33301 US
www.citiprogram.org

Generated on 02-Apr-2024. Verify at www.citiprogram.org/verify/?w84c27471-51d5-4c08-ba5e-b85a1a9aa06a-50970216

CITI PROGRAM

Completion Date 11-Sep-2022
Expiration Date N/A
Record ID 50970217

This is to certify that:

Linh Luu

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Information Privacy Security (IPS)
(Curriculum Group)
Students and Instructors
(Course Learner Group)
1 - Basic Course
(Stage)

Under requirements set by:

Gwynedd Mercy University

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CITI PROGRAM

Completion Date 28-Aug-2022
Expiration Date 27-Aug-2025
Record ID 50970216

This is to certify that:

Linh Luu

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Social & Behavioral Research - Basic/Refresher
(Curriculum Group)
Social & Behavioral Research
(Course Learner Group)
1 - Basic Course
(Stage)

Under requirements set by:

Gwynedd Mercy University

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CITI PROGRAM

Completion Date 04-Sep-2022
Expiration Date 03-Sep-2025
Record ID 50970219

This is to certify that:

Linh Luu

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Social and Behavioral Responsible Conduct of Research
(Curriculum Group)
Social and Behavioral Responsible Conduct of Research
(Course Learner Group)
1 - RCR
(Stage)

Under requirements set by:

Gwynedd Mercy University

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Fort Lauderdale, FL 33301 US
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