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Structural-Symbolic Translation Fluency: Reliability, Validity, and Usability

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A dissertation

presented to

the faculty of the Department of Educational Leadership & Policy Analysis

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Doctor of Education in Educational Leadership

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by

Matt C. Hoskins

May 2016

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Keywords: Mathematics, Curriculum-Based Measurement, Problem Solving

## ABSTRACT

### Structural-Symbolic Translation Fluency: Reliability, Validity, and Usability

by

Matt C. Hoskins

Standardized formative mathematics assessments typically fail to capture the depth of current standards and curricula. Consequently, these assessments demonstrate limited utility for informing the instructional implementation choices of teachers. This problem is particularly salient as it relates to the mathematical problem solving process. The purpose of this study was to develop and evaluate the psychometric characteristics of Structural-Symbolic Translation Fluency, a curriculum-based measure (CBM) of mathematical problem solving. The development of the assessment was based on previous research describing the cognitive process of translation (Mayer, 2002) as well as mathematical concept development at the quantitative, structural, and symbolic levels (Dehaene, 2011; Faulkner, 2009; Griffin, 2004).

Data on the Structural-Symbolic Translation Fluency assessment were collected from 11 mathematics and psychometrics experts and 42 second grade students during the spring of 2016. Data were analyzed through descriptive statistics, frequencies, Spearman-Brown correlation, joint probability of agreement, Pearson correlation, and hierarchical multiple regression. Psychometric features of interest included internal consistency, inter-rater reliability, test-retest reliability, content validity, and criterion-related validity. Testing of the 9 research questions revealed 9 significant findings. Despite significant statistical findings, several coefficients did not meet pre-established criteria required for validation. Hypothesized modifications to improve the psychometric characteristics are suggested as the focus of future research. In addition,

recommendations are made concerning the role of assessing the translation process of mathematical problem solving.

## DEDICATION

This work is dedicated to my family. Family is the institution that best reflects the worthiest characteristics of human kind. Without the provision of unconditional love and altruism demonstrated to me by family, this work would not have been pursued or completed. I thank my wife Courtney for pulling double duty on nights I was travelling the snowy roads to Tennessee or holed away at the kitchen table writing. I thank my children Stella and Holden for their understanding when I was not available to check math homework or play a game of basketball. I thank my mother and stepfather Vicky and Dr. Stephen Messier for their continual support, gentle nudging to get finished, and the faith that I would. Finally, I thank my father Craig Hoskins though lost much too soon, he instilled in me the virtues I hold dear.

## ACKNOWLEDGEMENTS

I would like to acknowledge and thank my dissertation committee, Dr. Eric Glover, Dr. Virginia Foley, Dr. Karen Keith, and Dr. James Lampley. Dr. Eric Glover, my committee chair, provided sage advice on how to structure and think through the development of the research. I am most thankful for his suggestions that required me to think outside of the theoretical orientations under which I had historically operated. Collectively, my committee provided unwavering support, guidance, and wisdom, for which I am deeply grateful.

I would like to acknowledge and thank Marty Erskine and Kelli Rhoads, two tremendous educators who epitomize what is right with the state of public education in the United States of America. Each of these teachers sacrificed their precious time, as they do daily for their students, to help with this project with the belief that it would benefit children and teachers. Without their support this work would have never been completed.

Finally, I am forever grateful to all of my public education teachers who chose the noble profession of education. Without those teachers a disengaged middle and high school student would have never realized and cherished this journey.

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## CHAPTER 1

### INTRODUCTION

As many states and districts are currently engaged in installation of Response to Intervention (RtI) as a means of overall school improvement, an obvious need is apparent for strong formative assessment tools in mathematics. Within RtI frameworks, Curriculum-Based Measurement (CBM) probes are often used at the elementary and middle school levels for universal screening and progress monitoring purposes. CBM is a prescriptive and standardized assessment that: (a) draws measurement materials from individual students' curricula; (b) incorporates ongoing measurement; and (c) is used to formulate instructional decisions (Tucker, 1987). In addition, CBM probes sample for a consistent pool of stimulus materials across the entire year's curriculum that allows for continuous measurement on a single scale over the period of a school year.

Despite these features current CBM probes for mathematics have typically been constrained to measurement of basic skill acquisition and have focused on these skills at the symbolic level. Due to the complexity of content and cognitive processes involved in broad mathematical achievement and the limited nature of CBM for mathematics, psychometric data reveal that CBM probes are typically less robust indicators of overall mathematics proficiency relative to those associated with reading (Christ, Scullin, Tolbize, & Jiban, 2008; Thurber, Shinn, & Smolkowski, 2002). In addition to more widespread implementation of RtI frameworks, the need for high quality formative assessment tools is developing parallel to implementation of new mathematics standards and curriculum in many states. Remaining true to the fundamental properties of CBM, it is important that the measures adequately sample the curriculum in which students are immersed.

The Common Core State Standards for Mathematics (CCSS-M) have been adopted by the majority of states and are currently a driving force for curriculum development. The CCSS-M reflects student proficiency as encompassing both procedural efficiency with standard algorithms, as well as student behaviors that promote the development of conceptual understanding of mathematics. Notably, for elementary mathematical problems within the domain of operations and algebraic thinking, the CCSS-M requires students to both represent and solve problems (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). The requirement for students to represent problems is aligned to the use of visual representations (Jitendra et al., 1998; Witzel, Mercer, & Miller, 2003; Woodward, 2006) and the use of underlying structure to solve word problems (Darch, Carnine, & Gersten, 1984; Fuchs et al., 2003; Xin, Jitendra, & Deatline-Buchman, 2005) which are both prevalent in the literature base of effective mathematic instruction. Given that the use of representation and structure is so prevalent in the research base, standards, and curriculum – it is conspicuously absent in current approaches to CBM in mathematics.

### **Statement of the Problem**

Current CBM probes for mathematics, including those associated with computation and concepts and applications, inadequately capture the breadth and depth of current mathematics standards and curricula. As a result CBM probes demonstrate limited utility for informing instruction, particularly as it relates to the mathematical problem solving process. The purpose of this study was to develop and provide preliminary evaluation into the psychometric properties of Structural-Symbolic Translation Fluency, a curriculum-based measure of mathematical problem solving for second grade students. The development of the probe was based on the literature describing the typical progression of mathematical concept development. It is

hypothesized that this structure for the assessment will lead to greater usefulness for second grade teachers. As a preliminary investigation into this instrument, the technical features of interest include reliability, validity, and usability as a screening instrument.

### **Research Questions**

The following research questions were used to guide this study:

1. Does the Structural-Symbolic Translation Fluency probe demonstrate internal consistency through split-half reliability estimates?
2. Does the Structural-Symbolic Translation Fluency probe demonstrate inter-rater reliability?
3. Does the Structural-Symbolic Translation Fluency probe demonstrate test-retest reliability?
4. Does a panel of mathematical content experts agree on the alignment between the assessment items contained within the Structural-Symbolic Translation Fluency probe and the Common Core State Standards for Operations and Algebraic Thinking in second grade?
5. Does a panel of mathematical content experts agree on the accuracy of computation situations, visual models, expressions, and equations used in the items contained within the Structural-Symbolic Translation Fluency probe?
6. Does the Structural-Symbolic Translation Fluency probe demonstrate concurrent convergent validity with the Number Knowledge Test?
7. Does the Structural Symbolic Fluency Total score account for unique variance on the Number Knowledge Test when controlling for the symbolic score?

8. Does the Structural Symbolic Fluency Total score account for unique variance on the Number Knowledge Test when controlling for the structural score?
9. Do teachers find the Structural-Symbolic Translation Fluency assessment useful for its intended purposes?

### **Significance of the Study**

The results of this study provide the initial evaluation into the psychometric features of a newly developed CBM probe of mathematical problem solving in second grade students. Unlike most CBM probes of mathematics that are limited to computation and math concepts at the symbolic level, Structural-Symbolic Translation Fluency requires the translation of mathematical word problems into a visual representation, as well as a symbolic expression or equation. This is aligned with both the current mathematical standards and research into the cognitive processes associated with mathematical problem solving and concept development. It is the purpose of the study to ascertain the psychometric features of Structural-Symbolic Translation Fluency in regard to use as a screener for difficulty with mathematical problem solving in second grade students. If the initial psychometric features meet widely accepted criterion standards (Gersten, Dimino, & Haymond, 2011), further evaluation into the instrument's use as a screening and progress monitoring tool would be beneficial.

In addition to the potential use of Structural-Symbolic Translation Fluency as a screening tool, the direct alignment to standards and concept development lends itself to limited use as a diagnostic instrument. The diagnostic matrix provided within the instrument may lend insight into particular computation situations that a student is having the most difficulty solving. The



results of the usability testing of this instrument will summarize the impressions of teachers related to the utility for informing instructional decision making. Moreover, “teaching to the test” often constrains and inhibits quality teaching. The format of this instrument may allow teachers to make teaching choices that are both research-based and of higher quality by making explicit connections between the language of word problems, visual representations, and symbolic expressions and equations.

Finally, the North Carolina Department of Public Instruction (NCDPI) is currently considering the development of a formative assessment system for students with disabilities to determine present levels of performance and monitor progress toward Individualized Education Program goals. In addition to these purposes districts in the state would have the option to use this system in a broader context as tools for screening and progress monitoring within a Multi-Tiered System of Support that is being implemented across North Carolina districts. If Structural-Symbolic Translation Fluency demonstrates adequate psychometric characteristics, it could be considered as one tool to be used within this larger assessment system.

### **Definitions of Terms**

The following definitions of terms are provided to ensure meaning and understanding of the study:

1. *Structural-Symbolic Translation Fluency*: A curriculum-based measure of mathematical problem solving in second grade that requires a student to match a word problem to a visual representation (in the form of a part-part-whole model) and an expression or equation. The problem types contained within the assessment are aligned to the common

computation situations found within the Common Core State Standards for Mathematics (CCSS-M). Word problems are read aloud by the teacher and students have 15 seconds to circle the corresponding visual representation and expression or equation.

2. *Curriculum-Based Measurement (CBM)*: Efficient, short-duration assessments administered for the purpose of examining static and dynamic student performance in fundamental content areas (Methe et al., 2011). CBM probes are typically used to screen for at risk students, examine the impact of core curriculum, and monitor student progress in response to instruction.
3. *Responsiveness to Instruction (RtI)*: an instructional and assessment framework with three fundamental components including multiples tiers of instruction, the use of a problem-solving model to make instructional decisions, and integrated data collection to inform decision making (Batsche et al., 2005).
4. *Translating*: Translating occurs when a student reads or hears a sentence from a problem and constructs a mental representation that corresponds to the sentence. The mental representation can be in verbal, symbolic, pictorial, or some other form (Mayer, 2002).
5. *Visual representation*: Visual representations include tables, graphs, number lines, and diagrams such as bar models, percent bars, and schematic diagrams that represent a mathematic structure or model (Woodward et al., 2012). The visual representation contained within the Structural-Symbolic Translation Fluency instrument is a part-part-whole model.
6. *Part-Part-Whole Models*: are pictorial representations of a mathematical word problem. Part-part-whole models can be used to represent multiple computation situations found within the Common Core State Standards of Mathematics.

## **Limitations and Delimitations**

The study is limited to evaluating initial aspects of technical adequacy for a curriculum-based measure to be used as a screening instrument. This study aims to validate the instrument's ability to predict which students may be at risk for mathematical problem solving. For this reason, further research would be required to ascertain validity within a comprehensive system of screening and progress monitoring. This study cannot determine the classification accuracy and predictive validity of the instrument or its sensitivity to growth over time. If initial estimates of reliability and validity meet acceptable targets, further research should be conducted. If initial targets for technical adequacy are not met, this evaluation process may lend insight into further modification of the instrument.

## **Overview of Study**

This study is organized into five chapters. Chapter 1 provides an introduction, statement of the problem, research questions, significance of the study, definitions of terms, and limitations and delimitations. Chapter 2 includes a review of the literature on the history and scope of mathematics instruction in the United States; the proficiency levels of students relative to national standards and international comparisons; the research base for mathematical problem solving, concept development, and procedural efficiency; the use of CBM in mathematics; and, the validation process required for CBM development. Chapter 3 identifies the research methodology including research questions, instrumentation, population, data collection, and data analysis. Chapter 4 contains the results of the study.

Chapter 5 provides a summary of the findings, conclusions, recommendations for further research, and recommendations for practice

## CHAPTER 2

### REVIEW OF LITERATURE

#### **Introduction**

This study was a preliminary investigation into the technical adequacy of a newly developed curriculum-based measure, Structural-Symbolic Translation Fluency. Within the context of states implementing Response to Intervention (RtI) and adopting new mathematical standards, the environment is ripe for validated and aligned formative assessment tools to guide instructional decision making. More broadly construed, new frameworks and standards are the consequence of a longstanding push for mathematics reform efforts. This chapter will document the factors contributing to and influencing these reform efforts, present the theory and research base used in the development of the Structural-Symbolic Translation Fluency instrument, describe the current strengths and limitations of formative assessment systems in mathematics, and detail the validation process required for a curriculum-based measure to be confidently used as a screening instrument.

The current picture of mathematics instruction across classrooms in the United States is varied and complex. Contentious debates have smoldered between theoretical orientations, with each side arguing passionately from its research base and philosophical point of view. The debate has been fueled by numerous factors, paramount among them socio-political forces and high profile educational policy statements, trends in research surrounding mathematics instruction, and the emergence and refinement of various learning theories (Woodward, 2004). On one side of the debate, the traditionalists have stressed the role of basic skill development as the structure supporting overall mathematical proficiency. This side has argued that mathematics is best

taught through teacher-directed approaches, and that students who struggle to grasp higher order mathematics do so because of deficiencies in operations with whole and rational numbers. In contrast, the reform minded, ardently supported by the National Council for Teachers of Mathematics (NCTM) (1989, 2000), has articulated an agenda of student-centered instructional practices that emphasize the construction of student knowledge through experience and discourse.

As the sides have each developed political and public faces, national and international assessments have invoked pause and question as to the United States' place in developing mathematically proficient and competitive students. While the Nation's Report Card, measured by the National Assessment of Educational Progress (NAEP), shows significantly stronger mathematical performance in fourth and eighth grade in 2013 than for all previous testing years, 58% of fourth graders and 64% of eighth graders performed below proficient. In addition, while racial and ethnic score gaps saw modest narrowing in fourth grade from the early 1990s to 2013, there was no significant narrowing between 2011 and 2013 (National Center for Educational Statistics, 2013).

In addition to the seemingly mediocre results of NAEP, a series of international comparative research studies indicates that performance in the United States is consistently bested by other nations. According to the most recent Trends in International Math and Science Study (TIMSS), the mean scaled score for fourth and eighth grade students in the United States was significantly higher than the overall mean score. However, eight countries scored significantly higher than the United States in fourth grade, and 11 scored higher in eighth grade (Provasnik et al., 2012). Converging evidence suggestive of the United States' lack of inclusion within the top tier of nations is the 2012 Programme for International Student Assessment (PISA) results that reveal

below average performance and an estimated rank of 27<sup>th</sup> among participating countries.

Notably, the PISA report indicated that 15-year-old students in the United States have specific weaknesses for problems with higher cognitive demands such as taking real-world situations, translating them into mathematical terms, and interpreting mathematical aspects in real-world problems (Organisation for Economic Co-operation and Development, 2012).

In the context of the mathematics reform movement, a multitude of explanations and criticisms have been waged on the results. Only recently, with the findings of the National Mathematics Advisory Panel (2008) as a precipitating factor, have standards and curricula transcended the debate and begun to take a more balanced approach to mathematics instruction, synthesizing the mutually beneficial aspects of both approaches. As an early proponent of such thought, Wu (1999) argued that, “‘Facts vs. higher order thinking’ is another example of a false choice that we often encounter these days, as if thinking of any sort –high or low- could exist outside of content knowledge” (p. 1). As this thinking resonates in the research base, its impact on the political and public debate remains to be seen.

Concerning the research surrounding high quality mathematics instruction and learning, the literature continues to expand exponentially. Recent approaches to understanding how students learn and make sense of mathematics have emphasized the role of an underlying number sense, which is thought to be inherent and hard-wired in human beings. Despite mankind’s propensity for the development and application of exceedingly complex mathematics, the theory posits that our brains process quantity and connect it to number in a rather rudimentary way. As such, it is the result of cultural creations such as language, a base ten number system, and symbols that allow for our greatest mathematical achievements (Dehaene, 1997). Interestingly, the research surrounding number sense demonstrates convergence with findings indicative of the benefits of

pairing conceptual understanding and procedural efficiency, and is now elucidating the role of concept development in the path to efficiency with mathematical procedures (Griffin, 2004; Mercer & Mercer, 1981).

While the research base is slowly evolving and coming to grips with the synthesis of two seemingly incongruent approaches to instruction, systematic formative assessment systems have lagged behind. Curriculum-based measurement (CBM), which has a robust literature base, has its roots in basic skill acquisition for mathematics (Deno, 1985; Shinn, 1989; Thurber et al., 2002). In addition, because current CBM probes that measure mathematical concepts and applications require students to first read the problems, there is sufficient evidence to conclude that performance on the test is confounded with students' reading skills (Marston, 1989; Thurber et al., 2002). It was the purpose of this study to develop an instrument that measured both concept development and skills acquisition, as well as reduce the confounding variable of reading proficiency.

### **The Mathematics Reform Movement (1950s – 2000s)**

A discussion of the mathematics reform movement is critical to this research because the history of the movement has informed current thinking surrounding the standards, curriculum, instruction, and assessment of mathematics. The construction of the instrument was completed under the guise that both conceptual understanding and procedural efficiency are the lynchpins to mathematical success. However, the mutually beneficial pairing of basic skills and conceptual understanding has not until recently been a widely accepted paradigm. In fact, it has been a circuitous path that characterizes the history of mathematics education, one that has traversed theoretical orientations ranging from teacher-directed instruction with an emphasis on procedural efficiency with standard algorithms to student-centered social-constructivist approaches



championing conceptual understanding developed through interaction and discourse. As the pendulum has repeatedly swung to each orientation, the debate has been sharply characterized as a dichotomy rather than a continuum. In addition, there have been multiple forces influencing the state of mathematics instruction including socio-political, research, and theoretical orientations that have played a predominant role (Woodward, 2004).

While the path has been a winding one, the stakes have been high. History provides a myriad of instances in which the sophistication of a nation's mathematical knowledge has led to prominence across a variety of fields. Nations that have demonstrated mathematical prowess are those that enjoy competitive advantages in keeping citizens healthy, creating technology to enhance their lives, developing a robust economy and financial markets, defending their interests, and quantitating past events to predict future outcomes (National Mathematics Advisory Panel, 2008). A defining illustration of the competitive advantage of mathematics can be taken from the Soviet launch of Sputnik in 1957. As a result of this historic event the United States responded with an unprecedented call to arms through a surge of federal research dollars aimed at the production of scholars, teacher educators, and highly trained mathematics teachers who would promote the United States as the paramount nation in engineering and scientific advancement.

Despite the broad recognition of the critical role of public education in developing the mathematical and technical dominance its citizens required for the nation's long-term success, a concurrently occurring phenomenon was taking place in which politicians and editorialists leveraged scathing criticism on the US education system (Hofmeister, 2004). While a strong public education system, particularly one that developed mathematics, science, and engineering

skills, was viewed as the conduit to the nation's prominence, it was also viewed as the root cause of its current failures.

With the confluence of the surge of research dollars and the volatile political climate, new ideas and curriculum were driven by the emerging theories of the time. Much of this work was in reaction to and diametrically opposed to the behaviorist schools of thought of the early 1950s that conceptualized effective mathematics instruction as the isolation of procedures in which teachers carefully control each step of the learning process. The behavioral orientation emphasized the automatic retrieval of informational bonds that should be obtained through systematic and explicit teacher-directed instruction with memorization and practice as primary teaching vehicles (Woodward, 2004). In response to this a growing referendum of university faculty and mathematics educators articulated a need for conceptual understanding and application of skills, which were described as best developed through students' active role in the construction of their understanding. In his summarization of the immediate post-Sputnik response, Shulman (1986) described this growing opposition to the fading influence of behaviorism on mathematics instruction:

The emphasis on beefing up the subject matter was matched with a strong concern for inquiry, discovery, and problem solving, for student-initiated activities and divergent thinking and for ascending the heights of Bloom's taxonomy. The opinion leaders were less concerned with the basic than with the more elevated understandings that are needed to be scientifically literate and competitive (p. 11-12).

As the movement progressed leadership roles were assumed in the large-scale curriculum development projects occurring at the University of Illinois Committee on School Mathematics, University of Illinois Arithmetic Project, and the School Mathematics Study group, all of which

were funded with federal dollars (Woodward, 2004). What emerged from this work in the late 1950s and early 1960s, commonly known as the *new math*, emphasized the teaching of abstract mathematical concepts in the elementary levels, particularly in areas related to set theory, alternate algorithms, and operations and place value. What is now most commonly represented as a product of the new math was student work in alternate base systems. The presumption was that if students had deep understanding of the base ten number system, it could be generalized to different base systems, and that student exploration in these alternate systems would mutually reinforce the understanding of base ten.

In addition to the shift of content, there was a predominant shift in pedagogy taking place. Theories of gestalt psychology (Rappaport, 1966) expressed the argument that instruction should be organized around part-whole relationships inherent to mathematics and that student unearthing of such relationships would preclude the need for rote memorization. These ideas were further developed and refined in the field of developmental psychology (Piaget, 1970; Vygotsky, 1981). Predominant to these theories was the use of manipulatives in math courses that allowed students to experience mathematics at a concrete level while developing their understanding of mathematical concepts and structures. Perhaps regrettably, this type of instruction was coined with the term *discovery*, which led to an assumption and misperception that placing a set of manipulatives in front of children was the extent of the instructional practice (Woodward, 2004). However, as Riedesel (1967) described it, the theory held that for manipulatives to be used effectively there would need to be carefully constructed situations designed to guide student learning. In a more recent iteration Ball (1992) elegantly noted:

My main concern about the enormous faith in the power of manipulatives, is their almost magical ability to enlighten, is that we will be misled into thinking that mathematical

knowledge will automatically arise from their use. Would that it were so! Unfortunately, creating effective vehicles for learning mathematics requires more than just a catalogue of promising manipulatives. The context in which any vehicle - concrete or pictorial - is used is as important as the material itself (p. 18).

As the late 1960s and early 1970s arrived, the purported promise of the new math was never fully realized. Elementary students struggled to grasp the abstract concepts and professional development efforts were insufficient in scope and largely unsuccessful in achieving the level of teacher understanding required for teaching the new curriculum. As the majority of teachers had been taught through the behaviorally oriented procedural approaches, it was a monumental shift in mindset surrounding content and pedagogy. Aligned with new math's perceived failure, and as a consequence of that, the political climate shifted once again.

As federal funds became contingent on experimental designs, it fostered the back to basics movement that ushered in the 1970s. In an attempt to describe educational research as more "scientific", standardized testing became a prominent term in the lexicon of both politics and education and laid the foundations for the current accountability movement. Corresponding with the widespread use of standardized testing was also the growing concern of inequity in mathematics education, as significant disparities were found between children living in poverty, who were predominantly African-American, and children from higher socioeconomic classes.

The brutally obvious achievement gaps in mathematics provided some of the kindling for the Johnson administration's war on poverty. The administration's commitment to projects with the potential to foster educational equity was crystallized through federal funding of research (Woodward, 2004). As the federally funded projects followed, with continued preference for experimental and quasi-experimental designs, the pendulum lurched further towards the

pedagogical practices that lent themselves best to conducting such research, behaviorally oriented teacher-directed instruction.

One of the most notable and largest projects of early education that emerged during this time was Project Follow Through. The project examined the impact of several instructional models on students from economically disadvantaged settings. The results of this study provided evidence for the use of direct instruction approaches, at least in terms of student outcomes on standardized tests. This work persuaded the political movement; however, a new framework emerging from the cognitive psychology literature was expanding the research base and was in conflict with the conclusions. In fact, this research base would ultimately provide one of the strongest counter-arguments to the recommendations of one of the most pejorative reports in the nation's history concerning the state of public education, *A Nation at Risk* (National Commission on Excellence in Education, 1983).

While *A Nation at Risk* continued to politically motivate the back to basics movement from the 1970s, the growing cognitive psychology literature base and policy statements from the National Council for Teachers of Mathematics (NCTM) (1989) provided a stark contrast. Instead of the large scale studies using experimental designs and quantitative analysis, cognitive psychology was interested in in-depth qualitative studies that examined how students process mathematics, particularly related to how students approach solving problems. As a result of the interest in information processing theory, practices emerged that involved the use of visual representation (Woodward, 2004) as an aid to understanding and the role of reflective thinking during problem solving, later termed *metacognition* (Skemp, 1987). As the research base grew and the theory evolved, so did the inclination of the researchers to support student-centered approaches to learning and problem solving.

As noted, this inclination was supported by the largest organization representing public school math teachers, NCTM, which published the *Curriculum and Evaluation Standards* in 1989. While one intended function of the document was to articulate a cohesive set of curriculum standards, the document was also inclusive of the process of instruction, expounding upon the role of problem solving, reasoning, connections (between both the mathematical concepts and real world applications), and the communication of mathematics through language. In retrospect, the standards have been argued to be grounded in the cognitive research of the time (Schoenfeld, 2002), while others decried that the recommendations were speculative and the evidence-base was thin (Hofmeister, 2004). Notwithstanding, the National Science Foundation supported a number of studies on reform curriculum aligned to the standards during the early 1990s.

Concurrently, the 1990s ushered in a time in which educators had to rethink the skill set their students would require to successfully navigate the job market. A previously obscure network of computers, later to be known as the internet, was transforming global communication and access to information. In addition, computer software replaced the reliance on computation skills for many jobs and the use of spreadsheets to model complex mathematics became common requirements for many entry level positions. The discourse surrounding the evolution described the postindustrial economy transitioning into an information economy, with a high premium on *knowledge workers*. In other words, basic skills were no longer sufficient for gainful employment; the new economy required individuals to be proficient with computer technology and high levels of mathematical literacy (Woodward, 2004).

## **The National Mathematics Advisory Panel**

In response to the transitioning economy, an executive order by President George W. Bush led to the creation of the National Mathematics Advisory Panel in 2006. The charge of the panel was, "...to foster greater knowledge of and improved performance in mathematics among American students...with respect to the conduct, evaluation, and effective use of the results of research relating to proven-effective and evidence-based mathematics instruction (National Mathematics Advisory Panel, 2008a, p. 7)". Prior to doing so, the report conveyed a call to action and described sobering statistics concerning the current state of mathematical literacy. For example, the report cited Philips (2007), in noting that 78% of adults were unable to compute interest paid on a loan, 71% were unable to calculate miles per gallon, and 58% were unable to calculate a 10% tip for a meal. The concerns expressed by the panel crystallized the critical role of mathematics in social and economic equity and described the pathway to mobility it would provide in the future economy. Often times the report made bold predictions concerning the future status of the United States' economy if reform efforts were not realized. For example, in the panel's assertion that the science, technology, engineering, and mathematics pipeline from universities would not meet the demands of the United States economy, it stated "ignoring threats to the nation's ability to advance in the science, technology, engineering, and mathematics (STEM) fields will put our economic viability and our basis for security at risk (National Mathematics Advisory Panel, 2008a, p. 2)."

While the call for reform by the panel was stalwartly articulated, the approach to reform and response was decidedly more measured. The panel provided a series of recommendations that if enacted were predicted to improve readiness for algebra. In doing so, the panel described critical foundations that included fluency with whole numbers, fluency with fractions, and particular

aspects of geometry and measurement. In addition to these critical foundational clusters, the panel developed key benchmarks within each cluster. That panel surmised that if these benchmarks were judiciously placed in the grades preceding algebra, students would have the best opportunity for preparation. In doing so, the panel clearly articulated that the benchmarks were justified based on a review of national and international curricula, and they were not derived from empirical research (National Mathematics Advisory Panel, 2008b).

Concerning fluency with whole numbers, the panel called for students to leave elementary school with a “robust sense of number” that includes an understanding of place value and the composition and decomposition of whole number. Notably, the panel emphasized the role of basic operations such as the understanding and application of basic properties including distributive, commutative, and associative properties. Furthermore, the findings highlighted the critical importance of computational facility that rests upon automaticity with number facts including addition and related subtraction facts and multiplication and related division facts (National Mathematics Advisory Panel, 2008b).

In addition to fluency with whole numbers, the panel also described the role of rational number reasoning and students’ ability to work fluently with fractions. In fact, the panel described that, “difficulty with fractions (including decimals and percent) is pervasive and is a major obstacle to further progress in mathematics, including algebra (National Mathematics Advisory Panel, 2008, p. xix). Concerning fractions, the panel articulated that students should possess the ability to locate positive and negative fractions on a number line, hence, demonstrating knowledge of fractions as a quantity that falls between two whole numbers. To facilitate progress in more complex mathematics the panel stated that students should be able to



apply understanding of fractions in contexts in which they naturally occur, such as describing rates, proportionality, and probability (National Mathematics Advisory Panel, 2008b).

In the final cluster the panel described particular aspects of geometry and measurement critical to algebra success, specifically detailing students' work with similar triangles. For example, the panel described how the slope of a straight line and linear functions have logical connections to the properties of similar triangles. In addition, the panel recommended that students engage in experiences analyzing properties of two- and three-dimensional shapes that reinforce the use of formulas to ascertain measurements such as perimeter, area, volume, and surface area. Furthermore, connections were made between exercises in finding unknown lengths, angles, and areas and high school algebra (National Mathematics Advisory Panel, 2008b).

In the findings of the panel it is noteworthy that the recommendations concerning the content of instruction, as well as pedagogical practices, crossed boundaries of the traditional and reform-minded debate. Moreover, the panel was forceful in its declarations that both sides offered value and describing the debate itself as unproductive. For example, related to content the panel stated,

Debates regarding the relative importance of conceptual knowledge, procedural skills (e.g., the standard algorithms), and the commitment of addition, subtraction, multiplication, and division facts to long-term memory are misguided. These capabilities are mutually supportive, each facilitating learning of the others. Conceptual understanding of mathematical operations, fluent execution of procedures, and fast access to number combinations together support effective and efficient problem solving (National Mathematics Advisory Panel, 2008a, p. 26).

In addition to the panel's attempt to mitigate the ferocity of the debate surrounding content, it also specifically addressed pedagogical issues through the finding of common ground. For instance, the panel argued that recommendations that instruction should be completely student-centered or teacher-directed were not supported by their review of the research. In fact, they stated both approaches were necessary and there was no compelling scientific research to support exclusive use of a single approach (National Mathematics Advisory Panel, 2008a).

While the recommendations of the National Math Panel initially struggled to gain traction in their impact on the political debate, curriculum, and instruction, one argument of the panel began to take hold. In examination of international comparative research, the panel noticed similarities in countries that consistently outperformed the United States, particularly in regard to the academic standards employed. In one of its recommendations, the panel stated that, "A focused, coherent progression of mathematics learning, with an emphasis on proficiency with key topics, should become the norm in elementary and middle school mathematics curricula (National Mathematics Advisory Panel, 2008a, p. 22). This recommendation was congruent to others made concurrently by large organizations with influence over policy efforts. For example, the National Governor's Association and Council of Chief State School Officers (CCSO) were also preparing a document with a similar call for action that served as a primary impetus for the Common Core State Standards.

### **Development of Common Core State Standards - Mathematics**

Within the same year as the release of the National Mathematics Advisory Panel's Final Report, the National Governor's Association, CCSO, and Achieve released, *Benchmarking for Success: Ensuring U.S. Students Receive a World-Class Education*. The report accentuated a call for policy reform with an initial recommendation to, "upgrade state standards by adopting a

common core of internationally benchmarked standards in math and language arts for grades K-12 to ensure that students are equipped with the necessary knowledge and skills to be globally competitive” (National Governors Association, CCSO, & Achieve, 2008, p. 24). This document served as the initial kindling to the Common Core State Standards Initiative, which was conceived in 2009, and created a goal to develop what are described as college and career ready standards. The idea of national standards was not new and one that has continually emerged and faded since the inception of the U.S. Department of Education in 1980.

While it is not the researchers intent to detail the longstanding history of factors contributing to the development of the Common Core State Standards, key legislation buttressing their development is salient to this discussion. The enactment of No Child Left Behind (NCLB) in 2002 resulted in strict accountability requirements, with an emphasis on standardized testing, that was intended to close the achievement gap. As the legislation resulted in sanctions for schools identified as “in need of improvement”, the result was an increase in finding loopholes to the legislation across the nation (Association for Supervision and Curriculum Development, 2012). In order to prevent large number of schools receiving such sanctions, some states redefined proficiency by lowering academic standards and cut scores on standardized assessments. As these states purveyed the image of success based on NCLB’s calculation of Adequate Yearly Progress (AYP), their students were not high achieving on other assessments of college readiness, such as the ACT and on the National Assessment of Educational Progress.

In response to the lack of consistency for defining proficiency across states, a broad coalition of policy groups and states joined together for a potential remedy. With a political selling point of higher, clearer, and more focused expectations, 48 states initially pledged to participate in the development of the standards within months of the initiative being announced (Association for

Supervision and Curriculum Development, 2012). As the states pledged support the National Governor’s Association and CCSSO implemented a process for developing standards with the inclusion of public comment periods, advisory groups from Achieve, ACT, the College Boards, The National Association of State Boards of Education, and the State Higher Education Executive Officers (Association for Supervision and Curriculum Development, 2012). Upon public discussion of draft versions of the standards in September 2009 and March 2010, the final standards were released in June 2010.

The development of Common Core State Standards for Mathematics (CCSS-M) built upon existing standards, taking into account publications by the National Council for Teachers of Mathematics and the benchmarks established by the National Mathematics Advisory Panel. The CCSS-M authors described three major shifts in the development of the standards that included a greater focus on fewer topics, increased coherence, and increased rigor (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Concerning greater focus, the standards highlight key work at each grade level that progressively develops across: concepts, skills, and problem solving related to addition and subtraction; concepts, skills, and problem solving related to multiplication and division of whole numbers and fractions; ratios and proportional relationships and early algebraic expressions and equations; arithmetic of rational numbers; and, linear algebra and linear functions. The language of the focused content is often consistent with that of the National Mathematics Advisory Panel recommendations and denotes both, “a solid understanding of concepts, a high degree of procedural skill and fluency, and the ability to apply the math they know to solve problems inside and outside the classroom (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010, “Key Shifts in Mathematics,” para. 2).

The CCSS-M authors also describe a shift related to increased coherence, operationalized as the connection of mathematical topics and thinking across grade levels. Rather than present mathematics as a disconnected set of procedures to be mastered through the memorization of tricks or mnemonics, the CCSS-M posits “coherent progressions from grade to grade” (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010, “Key Shifts in Mathematics,” para. 3). As stated, the development of the standards occurred through the lens of learning progressions, or trajectories, that are described as,

empirically supported hypotheses about the levels or waypoints of thinking, knowledge, and skill in using knowledge, that students are likely to go through as they learn mathematics and, one hopes, reach or exceed the common goals set forth for learning (Daro, Marsho, & Corcoran, 2011).

Based on this definition, progressions differ from traditional approaches of scope and sequence in that they are based on observational findings of the pathways by which students most commonly learn and understand mathematics rather than the disciplinary logic or common wisdom that commonly guides the sequence of instruction. Though the draft progressions used for the development of the CCSS-M rarely demonstrate evidence of empirical support, the authors argue that widespread adoption of the standards fosters the context in which large scale studies can be conducted to inform and refine the progressions. (Daro et al., 2011).

The final key shift described by the common core authors involves increased rigor, with equal emphasis on conceptual understanding, procedural skills and fluency, and application. In regard to conceptual understanding, the standards articulate its necessity across key concepts such as place value and ratios, and the Standards for Mathematical Practice highlight student behaviors that are reflective of the development of such understanding. Concerning procedural skills and

fluency, the recommendations of the National Mathematics Advisory Panel are echoed, with the CCSS-M authors describing the role of speed and accuracy in calculation. The authors note that core functions such as single-digit multiplication are critical to performing more complex procedures and algorithms and provide access to more complex concepts and procedures. In addition, the authors describe the role of practice in developing, maintaining, and generalizing such skills, while noting that some students will require more practice than others (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010, “Key Shifts in Mathematics,” para. 4).

### **The Role of Teacher Content Knowledge**

As the unproductivity of the mathematics reform debate was explicitly articulated in the findings of the National Mathematics Advisory Panel and the key shifts of the CCSS-M, the debate characterizing mathematical reform as a dichotomy between two diametrically opposed points of view is now becoming largely muted. The debate itself seems to have existed largely in a vacuum of space unique to the United States, with the international mathematics teaching community historically embracing the pairing of conceptual understanding and procedural efficiency. In fact, comparisons to the international teaching community were cited in both the panels’ call for reform and the standards authors’ call for adoption. Liping Ma’s (1999) *Knowing and Teaching Elementary Mathematics*, a study of the mathematical content knowledge of Chinese and American teachers, was among the first to gain popular notoriety in the teaching community and is one of most influential works highlighting an international perspective. Her discussion of how Chinese teachers negotiated the mathematical rationale of an algorithm, paints a clear picture to the connections between conceptual understanding and procedural efficiency.

Case in point, she describes an old saying that was frequently cited in her interviews with Chinese teachers, “Know how, and also know why” (Ma, 1999, p. 108). In her detailed description of the interviews Ma (1999) continues, that Chinese teachers encouraged students to find a reason behind an action, and an expectation existed for them to know how to carry out an algorithm as well as understand why it made sense mathematically. She noted, “From the Chinese teachers’ perspective, however, to know a set of rules for solving a problem in a finite number of steps is far from enough – one should also know why the sequence of steps in the computation makes sense (p. 108).

Ma’s book was not without controversy and criticism (Bracey, 2000), but it propelled the mathematics teaching community in the United States to become cognizant of the content and pedagogical practices of other nations and examine the strengths and weaknesses of American teachers in a new lens. In doing so it exposed a giant hurdle for improving mathematics instruction, teachers’ deep understanding of the content and their ability to teach mathematics in new ways. While Ma’s work was often incorrectly characterized as concerned with only the content of teaching mathematics, Shulman’s forward of the book describes that its, “conception of content is profoundly pedagogical” (p. xi). Exemplified by teachers’ responses to mathematical questions and teaching scenarios, Ma hypothesized that a profound knowledge of mathematics is a precursor to a teacher’s ability to instruct critical ideas to students and make connections across concepts. In her interviews with American teachers, she found that they did not display such understanding, which severely limited their ability to respond to student questions through accurate mathematical investigation. Ma concluded in her text that the knowledge gap she found between Chinese and American teachers was a likely cause of a similar gap found between mathematical achievement of American and Chinese students.

In the years following researchers tested the hypotheses surrounding the association between teacher content knowledge and student achievement through quantitative approaches. These studies were completed through proxies as well as direct assessment of teacher understanding. When proxies of teacher knowledge were used, the findings were generally mixed (Goldhaber & Brewer, 2000; Rowan, Correnti, & Miller, 2002). However, more robust associations were found when teacher content knowledge for teaching was measured directly. For example, Hill, Rowan, and Ball (2005) found that teachers' mathematical knowledge was significantly related to student achievement gains after controlling for student- and teacher-level covariates. Furthermore, they found that direct measurement of mathematical content knowledge for teaching were superior to indirect measures such as credit hours and experience when predicting student achievement. In one of their models they found that for each standard deviation's difference in teachers' mathematics content knowledge, students gained roughly two and a quarter points on the Terra Nova, translating to one half to two thirds of average monthly growth per standard deviation different. In finding such, the construct of content knowledge for teaching mathematics became prominent in the literature and was viewed as a key variable for improving mathematics instruction and student achievement.

In detailing the structure of the mathematical content knowledge for teaching, Ball, Thames, and Phelps (2008) described the construct as comprised of four domains. First, *common content knowledge* refers to a general understanding of mathematics that is used in settings other than teaching. This type of knowledge is critical for teachers to know the content they teach; however, it is knowledge that is not unique to the field of teaching. For example, common content knowledge includes using terms and mathematical notation correctly, which are mathematical skills required for teaching, but is also knowledge possessed by those outside of



the profession. The second domain includes *specialized content knowledge*, which is mathematical knowledge that is not typically needed outside of teaching. For example, it requires various interpretations and understanding of operations, such as “take-away” and “comparison” models of subtraction and “joining” and “comparison” models of addition. Such knowledge is critical to the subtle, yet critically important, precision that is required when teaching operations and in the responses to students who demonstrate misunderstanding. The third domain is constructed from *knowledge of content and students*, consisting of knowledge that combines understanding mathematics and students. This type of knowledge is critical when teachers engage in tasks such as anticipating what students will likely find confusing, predicting what students will find engaging and motivating, and interpreting students emerging and incomplete thinking through their expression of language. Finally, the final domain is derived from *knowledge of content and teaching*. This last domain combines knowledge around mathematics and teaching, for situations such as designing instructional tasks with appropriate sequencing, selecting appropriate examples and nonexamples, and evaluating various representations that would best convey a key mathematical idea.

Mathematical content knowledge for teaching is an important consideration in anticipating the utility of the Structural-Symbolic Translation Fluency instrument. As the construct appears to be associated with instructional implementation choices that lead to higher student achievement, it is hypothesized that those teachers with stronger content knowledge for teaching may use the instrument more effectively. If the instrument is validated as a screening instrument, a necessary condition for its role in improving student achievement will hinge upon a teacher’s ability to understand and address the barriers to students’ difficulty in translating mathematical situations presented through language into a structural and symbolic representation. It seems likely that a

deep understanding of the computation situations that are presented, the various representations of the structures and expressions or equations that could represent them, and the relationships across them would promote effective use of the instrument. For example, the ability to anticipate student barriers and sequence instruction to develop student understanding that put-together addend unknown problem types can be answered through the process of subtraction, or the inverse of addition with a missing addend, appears to fall within the realm of the construct.

The role of teacher mathematics knowledge for teaching is also critical to the discussion of the mathematics reform movement, particularly related to teacher preparation and professional support. While the majority of public debate has focused on the manipulation of content and pedagogy for improving student outcomes, a lesson from the history of the reform movement is that changes in such practices are typically unfruitful due to a lack of accompanying professional development (Woodward, 2004). While its impact complicates the role of policy in improving mathematics instruction, the promise of such a perspective rests in the idea that high quality teaching is not an innate feature and that mathematical content knowledge for teaching can be developed through preservice and in-service learning. In fact, such findings were demonstrated by Faulkner and Cain (2013) when they found that teachers participating in a five day professional development module that focused on number sense made significant gains in their mathematical content knowledge for teaching. The authors stated that the focus of number sense was used for the purpose of coherence to develop teachers abilities for, “connecting mathematical ideas that teachers in the United States often treat as separate topics” (p. 117). While the role of number sense has found growing influence in the mathematics education literature, this example is unique to an operationalized structure of number sense that can be used

for the intent of improving teaching through implementation choices and connecting key concepts.

### **Number Sense and Instructional Implications**

The mathematics reform debate has reached a culmination where for the first time in its history common ground is consistently articulated through policy, standards, and curriculum. As for the landscape of this middle ground, the terrain is becoming less ambiguous, with the operationalizing of the construct of number sense becoming prevalent in the literature base. While still in the throes of the debate, Gersten and Chard (1999) stated, “Our model indicates how the number sense concept provides a sensible middle ground in what is becoming an increasingly heated controversy about how to teach mathematics” (p. 18). In their description of number sense, it is introduced as an analog to the role of phonemic awareness in reading. Just as a child’s development of the insight that words are composed of individual units of sound seems to be critical to the subsequent development of more complex decoding and fluency skills, they proposed that a basic number sense in early mathematics is the bedrock to more complex mathematical thinking. In their definition, number sense refers to, “a child’s fluidity and flexibility with number, the sense of what numbers mean, and an ability to perform mental mathematics and look at the world and make comparisons” (p. 19-20).

In detailing the acquisition of number sense, Gersten and Chard (1999) propose that most children acquire number sense informally through interactions with family members prior to formal schooling. However, for those students who fail to develop an adequate sense of number, they require explicit and formal instruction. This conclusion is consistent with the findings of

Griffin, Case, and Seigler (1994), who through their examination of the Rightstart program (currently named Number Worlds) determined prerequisite skills necessary for the formal learning of arithmetic. As a result of the emerging research base surrounding number sense, Gersten and Chard (1999) interpret the implications for teaching through the submission that,

...simultaneously integrating number sense activities with increased number fact automaticity rather than teaching these skills sequentially...appears to be important for both reduction of difficulties in math for the general population and for instruction of students with learning disabilities (p. 20).

From this perspective drill and practice of math facts is insufficient without the explicit development of an underlying number sense. Based on this assumption, the purpose of the Structural-Symbolic Translation Fluency instrument is to ascertain students' connection between the language of a mathematical situation and the operation, a process that is hypothesized to be a substrate of number sense.

For example, approaching number sense from the neuropsychological perspective, Dehaene describes the construct as a result of the slow evolution the human brain, making it "a primitive number processor" (p. 4) that has been slow to adapt to the cultural creations of language and other symbolic representation of mathematics. From this standpoint, number sense can be analogous to an accumulator model in which a cylinder filling with units of water can only be interpreted and processed in small quantities. While decidedly limited in its innate processing of quantity, this model represents a new dimension of perception, as perceiving the cardinality of a small set of objects is parallel to perceiving their color, shape, or position. In fact, subitizing, the immediate apprehension of a quantity that occurs without counting (Clements, 1999), can be interpreted as evidence of this innate ability to process small quantities and connect it to number.

From these perspectives, the realm of mathematics falls in human's ability to connect concrete quantities that exist in time and space to language and symbols that can accurately describe and abstract situations.

In her description of number sense and its implications for teaching, Griffin (2004) more explicitly makes the connection between quantity, language, and symbols by defining the construct in this fashion:

The discipline of mathematics comprises three worlds: the actual quantities that exist in space and time; the counting numbers in the spoken language; and formal symbols, such as written numeral and operation signs. Number sense requires the construction of a rich set of relationships among these worlds. Students must first link the real quantities with the counting numbers. Only then can students connect this integrated knowledge to the world of formal symbols and gain an understanding of their meaning (p. 40).

The implications for teaching are explicit connections during instruction from quantity, to the language or structure of the problem, and finally to the symbolic representation. In similar fashion Witzel et al., (2003) describe how this can be done through a concrete-to-representational-to-abstract (CRA) sequence of instruction. CRA instruction begins with students interacting with manipulative objects to represent mathematical situations. Once the concepts are understood through the manipulation of objects, the same concept is worked through with visual or pictorial representations. Finally, students link the visual representation to mathematical symbols. Such an instructional sequence has been found to be effective for arithmetic (Miller & Mercer, 1993) as well as models of algebra instruction (Witzel et al., 2003).

## **Schema-Based Instruction and Translating**

These instructional approaches show promise in the specific areas in which they have been evaluated and further clarify the bridge that links conceptual understanding to procedural efficiency. A related approach designed for students solving various types of word problems, including those involving addition, subtraction, multiplication, division, and proportional thinking is schema-based instruction (Jitendra & Hoff, 1996; Jitendra et al., 2011; Xin et al., 2005). When making connections from language to visual representation to symbols for solving mathematical word problems, schema-based models emphasize the elements of a problem's semantic characteristics to students' ability to solve them. As opposed to "key word" strategies that program students to determine operations based on surface level features of the problem (Parmar, Cawley, & Frazita, 1996), schema-based instruction and acquisition of the schema by the student allows for, "the learner to use the representation to solve a range of different (i.e., containing varying surface features) but structurally similar problems" (Xin, Jitendra, & Hoff, 1996, p. 182). During instruction involving schema-based instruction, there are general problem solving steps that are employed, which include: (a) reading to understand, (b) identifying the problem type and using the schema diagram to represent the problem, (c) transforming the diagram to a math sentence and solving the problem, and (d) looking back to check.

Within schema-based approaches, there are several cognitive problem solving processes that take place. Presuming a child's ability to read and understand the problem, a student must represent the language of the problem into a schema diagram and subsequently into a math sentence. In the cognitive psychology literature this process has been referred to as translating (Mayer, 2002). Mayer describes translating as the process in which a student reads or hears a mathematical problem and constructs a mental representation. This mental representation may

take different forms such as verbal, symbolic, or pictorial. The research base surrounding translation generally demonstrates that students have difficulty with this cognitive process, particularly when representing certain types of sentences. According to Mayer (2002) assignment sentence structures in which a value is explicitly assigned to a variable (e.g., Tom has seven apples) are more psychologically basic than relational sentence structures that express the quantitative relationship between two variables (e.g., Tom has seven apples. This is five fewer than Susie). Students typically have more difficulty in representing relational sentences as compared to assignment sentences, showing difficulty in the linguistic and schematic knowledge required for successful translation. As could be surmised, this is also found to interfere with students' ability to solve mathematical word problems (Hegarty, Mayer, & Monk, 1995).

The development of the Structural-Symbolic Translation Fluency assessment was based on a synthesis of the research surrounding number sense, concrete-to-representational-to-abstract instructional sequence, schema-based instruction, and cognitive problem solving models. It is the purpose of the assessment to determine a child's risk for mathematical problem solving, based on his or her ability to translate the language of a problem into an underlying visual structure and symbolic expression or equation. This is unique to most assessments that require the full problem solving process from reading, to translating, to execution of the computation. It is hypothesized that a predominant cause of problem solving difficulties in students rests in this translation process and as a result, students who perform poorly on the assessment would be subsequently at risk for broad mathematics achievement. In addition, if validated this instrument could provide more diagnostic information as to the breakdown of the problem solving process, and patterns revealed in error analysis could lend evidence of difficulties with specific problem types that require more explicit and systematic instruction.

## **Validation Process for Curriculum-Based Measures of Mathematics**

The Structural-Symbolic Translation Fluency assessment was conceived under the continuum of assessment known as formative assessment. The administration of formative assessment occurs before and during instruction with the intent of informing the process of learning (Black & Wiliam, 1998). On the continuum of formative assessment is a particular type of systematic assessment known as curriculum-based measurement (CBM). From its roots CBM was designed for use as a general outcome measure (GOM), an assessment that could serve as a broad indicator, or pulse, of broad academic achievement. GOMs represent critical outcomes of instruction because the skills they measure develop gradually over time, are closely associated with interrelated subskills, and predict success with more complex academic skills. CBM's utility for such purposes has been exemplified through oral reading fluency (Methe et al., 2011).

While the GOM approach to curriculum-based measurement has been met with success in reading, the findings have been less robust for mathematics. As a result there is growing doubt that the GOM model can be ported to mathematics because one skill set, such as computational fluency, fails to fully represent the curriculum (Methe et al., 2011). However, the common alternative involving the measurement of discrete subskills lack results in assessments that provide real time diagnostic information but do not possess the traits of a reliable or valid screening instrument. To account for this, Hosp, Hosp, and Howell (2007) articulated a link between GOM and subskill measurement. Structural-Symbolic Translation Fluency is hypothesized to represent this form of CBM, as the translation process is predicted to be one that grows more complex over time, corresponding to the problem types and situations that are required over the curriculum. However, it is also hypothesized to be broad enough for addition and subtraction that it will serve the function as a screening tool for second grade students.



In order to validate a CBM as a screening tool, a set of sequenced standards has been articulated by Clarke and Shinn (2004). Based on their guidelines, a measure first needs to meet pre-established criteria for reliability. If these criteria are met, the validity of the measure from a concurrent and predictive standpoint must be established. Finally, the measure's classification accuracy through estimates of sensitivity and specificity should be obtained. In addition, the usability of the instrument from the perspectives of teachers should be examined (Fuchs, 2004).

### **Development of the Structural-Symbolic Translation Fluency Probe**

The development of the Structural-Symbolic Translation Fluency assessment was based on a synthesis of previously described research surrounding number sense, cognitive problem solving models, and the features of curriculum-based measurement (CBM). For the initial validation process, the probe was constructed based on the Common Core State Standards- Mathematics Operations and Algebraic Thinking strand for second grade and involves addition and subtraction situations. For development of the 22 items, 11 different problem types were identified for inclusion (North Carolina Department of Public Instruction, 2015). These were:

- Add to- Result Unknown (e.g., Two bunnies sat on the grass. Three more bunnies hopped there. How many bunnies are on the grass now?)
- Add to- Change Unknown (e.g., Two bunnies were sitting on the grass. Some more bunnies hopped there. Then there were five bunnies. How many bunnies hopped over to the first two?)

- Add to- Start Unknown (e.g., Some bunnies were sitting on the grass. Three more bunnies hopped there. Then there were five bunnies. How many bunnies were on the grass before?)
- Take from- Result Unknown (e.g., Five apples were on the table. I ate two apples. How many apples are on the table now?)
- Take from- Change Unknown (e.g., Five apples were on the table. I ate some apples. Then there were three apples. How many apples did I eat?)
- Take from- Start Unknown (e.g., Some apples were on the table. I ate two apples. Then there were three apples. How many apples were on the table before?)
- Put Together/Take Apart- Total Unknown (e.g., Three red apples and two green apples are on the table. How many apples are on the table?)
- Put Together/Take Apart- Addend Unknown (e.g., Five apples are on the table. Three are red and the rest are green. How many apples are green?)
- Compare- Difference Unknown (e.g., Lucy has two apples. Julie has five apples. How many more apples does Julie have than Lucy?)
- Compare- Bigger Unknown (e.g., Julie has three more apples than Lucy. Lucy has two apples. How many apples does Julie have?)
- Compare- Smaller unknown (e.g., Julie has three more apples than Lucy. Julie has five apples. How many apples does Lucy have?)

For each problem type two word problems were developed with corresponding part-part-whole models and expressions and equations. For the comparison problem types, one word problem was constructed to include the word “more” and one problem was constructed to include the word “fewer”. In addition, eight of the 11 problem types could be solved using either addition or

subtraction. For these eight problem types, one expression or equation used addition and the alternate used subtraction. The use of “more” or “less” for comparison problem types and the expressions and equations representing addition and subtraction for the eight problem types were systematically counterbalanced across the probe. The part-part-whole model represents a visual representation of the underlying structure of the computation and the equation or expression represented the problem in symbolic (e.g., numerals and operators) form. In addition to corresponding part-part whole models and expressions and equations, two distractors (i.e., incorrect answer choices) for each item were also developed. It is the purpose of the assessment to ascertain ability to translate the language of the word problems into the structural (e.g., part-part-whole models) and symbolic models.

### **Summary**

Mathematics instruction across classrooms in the United States differs widely as a result of a contentious history of mathematics reform. Only recently with the emergence of the National Mathematics Advisory Panel and the implementation of Common Core State Standards has more measured discourse found common ground. Despite this the research base expounding upon how this coming to terms should be realized in the classroom is still developing classroom implications. Specifically, formative assessment approaches such as curriculum-based measurement (CBM) have lagged even further behind. The synthesis of what is known of number sense, the concrete-to-representational-to-abstract instructional sequence, schema-based instruction, mathematical problems solving, and the characteristics of CBM have informed the development of Structural-Symbolic Translation Fluency.

## CHAPTER 3

### RESEARCH METHODOLOGY

The purpose of this study was to develop and provide preliminary evaluation into the psychometric properties of Structural-Symbolic Translation Fluency, a curriculum-based measure (CBM) of mathematical problem solving for second grade students. The development of the probe was based on the literature describing the typical progression of mathematical concept development that happens first at a quantitative or concrete level, then at the level of mathematical structure and visual representation, and finally at the symbolic level through the use of digits and mathematical symbols (Dehaene, 2011; Faulkner, 2009; Griffin, 2004). As a preliminary investigation into this instrument, the technical features of interest include reliability, validity, and usability as a screening instrument. The results of the study will provide evidence to the measure's utility and inform future research on the role of assessing the translation process. This chapter describes the research methodology and design of this quantitative study. Research questions and null hypothesis, instrumentation, population, data collection, and data analysis are presented in this chapter.

#### **Research Questions and Null Hypotheses**

1. Does the Structural-Symbolic Translation Fluency probe demonstrate internal consistency through split-half reliability estimates?  
 $H_{01}$ . There is no significant positive correlation between split-half total scores.
2. Does the Structural-Symbolic Translation Fluency probe demonstrate inter-rater reliability?  
 $H_{01}$ . There is no significant agreement between two raters' Total scores.

3. Does the Structural-Symbolic Translation Fluency probe demonstrate test-retest reliability?

H<sub>01</sub>. There is no significant correlation between initial Total scores and Total scores obtained 2 weeks later.

4. Does a panel of mathematical content experts agree on the alignment between the assessment items contained within the Structural-Symbolic Translation Fluency probe and the Common Core State Standards for Operations and Algebraic Thinking in second grade?

A panel of experts does not agree that there is alignment between the assessment items contained within the Structural-Symbolic Translation Fluency anchor probe and the Common Core State Standards for Operations and Algebraic Thinking in second grade.

5. Does a panel of mathematical content experts agree on the accuracy of computation situations, visual models, expressions, and equations used in the items contained within the Structural-Symbolic Translation Fluency probe?

A panel of mathematical content experts does not agree on the accuracy of computation situations, visual models, expressions, and equations used in the items contained within the Structural-Symbolic Translation Fluency anchor probe.

6. Does the Structural-Symbolic Translation Fluency probe demonstrate concurrent convergent validity with the Number Knowledge Test?

H<sub>01</sub>. There is no significant correlation between the Structural-Symbolic Fluency Total scores and Number Knowledge test raw scores.

7. Does the Structural Symbolic Fluency Total score account for unique variance on the Number Knowledge Test when controlling for the symbolic score?

H<sub>01</sub>. The Structural Symbolic Fluency Total scores do not account for unique variance on the Number Knowledge Test raw scores when controlling for the symbolic score.

8. Does the Structural Symbolic Fluency Total score account for unique variance on the Number Knowledge Test when controlling for the structural score?

H<sub>01</sub>. The Structural Symbolic Fluency Total scores do not account for unique variance on the Number Knowledge Test raw scores when controlling for the structural scores.

9. Do teachers find the Structural-Symbolic Translation Fluency assessment useful for its intended purposes?

Teachers do not find the Structural-Symbolic Translation Fluency useful for its intended purposes.

### **Instrumentation**

For the evaluation of the instrument designed in this study, Structural-Symbolic Translation Fluency, a set of sequenced standards was followed as articulated by Clarke and Shinn (2004). First, the measure was evaluated for characteristics of reliability. The relevant characteristics of reliability that were examined included internal consistency, inter-rater reliability, and test-retest reliability. In addition to examining reliability relative to established criteria (Gersten et al., 2011), characteristics of validity were also examined. For the purpose of this study content and criterion-related validity were evaluated. For content validity the items on the assessment were reviewed by a panel of mathematics content experts, including teachers, state-level math consultants, and university faculty, to ascertain whether items contained within the Structural-Symbolic Fluency anchor probe aligned to the Common Core State Standards for Operations and Algebraic Thinking in second grade and if the problem types, part-part-whole models, and

expression or equations matched. For criterion related validity, concurrent validity with the Number Knowledge Test was measured, as well as divergent validity with Oral Reading Fluency. In addition, feedback from teachers concerning the utility of the instrument for making instructional decisions was also evaluated. After the preliminary evaluation was complete, further evidence of predictive validity and classification accuracy would be required to validate the instrument's use as a screener. In addition, supportive evidence of construct validity could be obtained through intervention studies with students to ascertain if students who had received intervention on the translation process performed better than students who had not received such intervention.

### **Population**

The population for this study included second grade students during the winter of the 2015-2016 school year. After obtaining IRB approval and informed consent, 42 students were selected from four classrooms based on a random sample of second grade students within two small rural districts in North Carolina. In both districts selected, teachers and superintendents expressed a willingness to participate in and approve the study. Once permission was obtained, two teachers were selected to administer the assessment.

### **Data Collection**

The researcher received permission from the East Tennessee State University Institutional Review Board and from the superintendents of each of the North Carolina school districts. Once permission was obtained the Structural-Symbolic Translation Fluency probe was electronically

sent to a panel of 25 math content experts for review. The panel was comprised of seven university faculty, six school psychologists, five state-level mathematics consultants, five district-level mathematics coaches, and two teachers. The panel members who responded reviewed the Structural-Symbolic Translation Fluency probe and provided feedback via an online survey. Based on the feedback, the researcher subsequently modified the corresponding equations or equations to eight items.

When the Structural-Symbolic Translation Fluency probe was finalized, 21 second grade students in each of the two school districts were randomly selected. Once selected, parental permission forms were sent home with the student for parent signature. At 1-week increments, additional students were selected and consent was sent home until the desired sample size was met. During the data collection process, student data were maintained through an anonymous coding system.

In order to obtain inter-rater reliability estimates, the researcher trained two teachers (one from each district) on the data collection process. Once trained, the teachers administered the Structural-Symbolic Translation Fluency probes to groups of up to 15 students under the researcher's supervision. After administration, the teachers independently scored the probes using the Structural-Symbolic Translation Fluency Scoring protocol. After the teachers scored the probe, the researcher independently scored the probes for comparison with the teacher's scores. In order to obtain concurrent convergent validity, the researcher administered the Number Knowledge Test individually to the sample of students immediately following the administration of the Structural-Symbolic Translation Fluency probe. The initial round of data collection occurred on consecutive days in the two school districts. In order to obtain test-retest



reliability estimates, the Structural-Symbolic Translation Fluency probe was administered by the researcher to the initial sample of students 2 weeks after the initial administration.

### **Data Analysis**

Data from Structural-Symbolic Translation Fluency and the Number Knowledge Test were analyzed through Spearman-Brown correlation, joint probability of agreement, Pearson correlation, and hierarchical multiple regression using the IBM-SPSS software. In addition, descriptive statistics, including means and standard deviations, were obtained. Data from brief surveys administered to the expert panel and the teachers who administered the Structural-Symbolic Translation Fluency assessment were analyzed for frequencies. A Spearman-Brown correlation was analyzed for research question 1, a joint probability of agreement was analyzed for research question 2, Pearson correlations were analyzed for research questions 3 and 6, hierarchical multiple regression analyses were analyzed for research questions 7 and 8, and frequencies were analyzed for research questions 4, 5, and 9.

To estimate the assessment's reliability, the following types of reliability were examined: internal consistency, inter-rater, and test-retest. Internal consistency was estimated through a split-half reliability estimate. The test items were split by odd and even items and a Spearman-Brown correlation was used (Allen & Yen, 1979). For inter-rater reliability, a joint probability of agreement was obtained to estimate how frequently two-raters agreed on scores for individual items. For test-retest reliability, a Pearson correlation was obtained for the Total scores of two administrations of the instrument, with the second administration occurring 2 weeks after the first.

For validity content validity and criterion-related validity were examined. Content validity was evaluated through a review of the items by a panel of experts that included university faculty, state-level consultants, school psychologists, and district-level mathematics coaches. For each item individual panel members completed a rating form measuring their extent of agreement to an item matching the proposed structural and symbolic representations. For criterion-related validity concurrent convergent validity was analyzed through Pearson correlations with the Number Knowledge Test. The Number Knowledge Test is a validated and widely used assessment of number sense for second grade students in North Carolina (Griffin, 2003). If desired content and criterion-related validity estimates are established, future research could be conducted to examine the predictive validity and classification accuracy of the instrument for end of second grade outcomes. In addition, further evidence of construct validity could be examined via an intervention study in which scores obtained by students who receive targeted instruction in the translation process are compared to students who have not received such intervention.

### **Summary**

This study provides preliminary evaluation into the psychometric properties of Structural-Symbolic Translation Fluency, a curriculum-based measure (CBM) of mathematical problem solving for second grade students. The sample was obtained through a random process in two rural districts in North Carolina. Spearman-Brown correlation, joint probability of agreement, Person correlation, hierarchical multiple regression, descriptive statistics, and frequencies were used to address the nine research questions.

## CHAPTER 4

### DATA ANALYSIS

#### **Introduction**

The purpose of this study was to develop and validate a mathematics assessment for the measurement of the translation problem solving process proposed by Mayer (2002). The results of this research provide preliminary evaluation into the psychometric properties of Structural-Symbolic Translation Fluency for use as a curriculum-based measure (CBM) of mathematical problem solving for second grade students. The theory from which the assessment was designed was based on literature describing mathematical concept development occurring at quantitative, structural, and symbolical levels (Dehaene, 2011; Faulkner, 2009; Griffin, 2004). As a preliminary investigation into this instrument's utility as a screening instrument, the technical features of reliability, validity, and usability were examined. The results of the study provide evidence of the assessment's psychometric features, its limitations, and informs future research on refinement of the instrument and the role of assessing the translation process. This chapter describes the data analysis and results of this quantitative study. Demographics and individual research questions are individually addressed within this chapter.

#### **Demographic Characteristics**

In order to measure content validity, the Structural-Symbolic Translation Fluency probe was electronically sent to a panel of 25 math content and psychometrics experts with an accompanying survey. The panel was comprised of seven university faculty, six school psychologists, five state-level mathematics consultants, five district-level mathematics coaches, and two teachers. Of the 25 experts who were contacted, 11 replied to the survey, resulting in a

response rate of 44%. The composition of the respondents was six state-level consultants (two of whom are licensed school psychologists), three university faculty, one practicing school psychologist, and one district-level coach.

The student sample included 42 randomly selected second grade students obtained from four classrooms within two rural school districts located in northwest and western North Carolina. Data obtained from three students (7%) were excluded from the study because they met pre-established exclusionary criteria. The excluded data were obtained from students who failed to respond to at least 25% of the assessment items. The total sample included 20 males (48%) and 22 females (52%). Parental consent was obtained from each student and an assent statement indicating voluntary participation was read to the students prior to the administration of the first assessment. All students in the sample chose to voluntarily participate in the study.

## **Reliability**

### **Research Question 1**

Question 1: Does the Structural-Symbolic Translation Fluency probe demonstrate internal consistency through a split-half reliability estimate?

H<sub>01</sub>: There is no significant positive correlation between split-half scores.

A Pearson correlation was initially computed to estimate the relationship between the odd and even items on the Structural-Symbolic Translation Fluency probe. The results of the analysis revealed a moderate positive relationship between the odd (M = 10.67, SD = 2.85) and even (M = 11.02 SD = 2.85) items on the Structural-Symbolic Translation Fluency probe and a

statistically significant correlation [ $r(39) = .60, p < .01$ ]. As a result of the analysis, the null hypothesis was rejected.

In addition, a Spearman-Brown correlation was computed to adjust the estimate produced by the Pearson correlation. The Spearman-Brown formula adjusts a Pearson correlation to estimate a test's reliability if the split-half test length was increased to the total length by adding parallel items (Allen & Yen, 1979). The results of the analysis revealed a moderate positive association between the odd and even items yielding a coefficient of .75. Despite the null hypothesis being rejected, the Spearman-Brown coefficient did not meet established standards for internal consistency that sets a minimum coefficient of .80 (Gersten et al., 2011). Figure 1 shows the scatterplot of students' odd and even scores on Structural-Symbolic Translation Fluency.

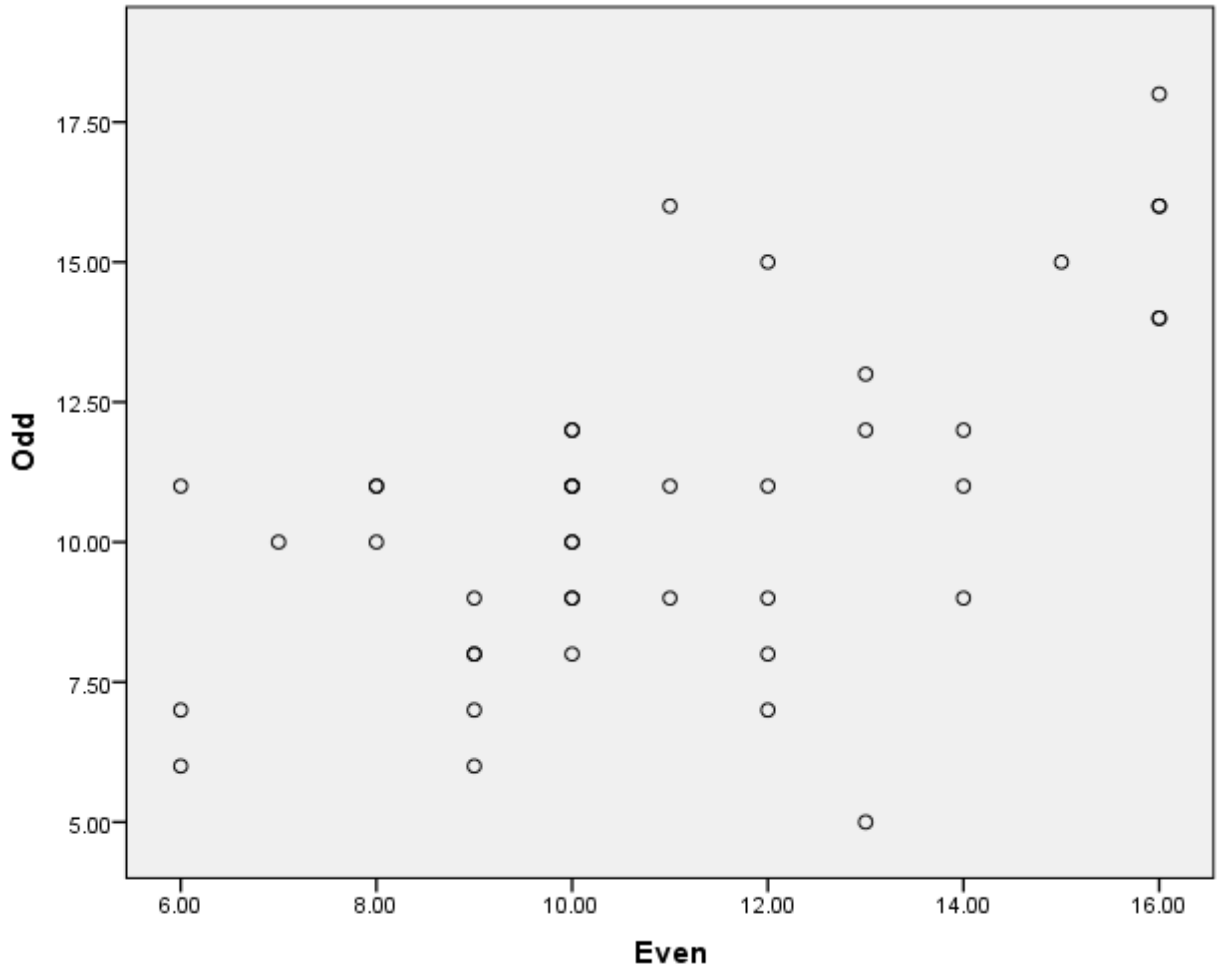


Figure 1: *Scatterplot of Students' Odd and Even Scores on Structural-Symbolic Translation Fluency*

### Research Question 2

Question 2: Does the Structural-Symbolic Translation Fluency probe demonstrate inter-rater reliability?

H<sub>02</sub>: There is no significant agreement between two raters' Total scores.

A joint probability of agreement analysis was computed to estimate the inter-rater reliability of the assessment. Each item on the assessment was scored by the administering teacher as well

as the researcher. The initial sample of 42 students resulted in 1,804 individual items that were scored by the two raters. Of the 1,804 items agreement was indicated for 1,779 items. Disagreement was indicated on 25 items. The resulting joint probability of agreement was .99. This coefficient met established standards for inter-rater reliability that sets a minimum coefficient of .90 (Gersten et al., 2011). As a result of this analysis the null hypothesis was rejected.

### **Research Question 3**

Question 3: Does the Structural-Symbolic Translation Fluency probe demonstrate test-retest reliability?

H<sub>03</sub>: There is no significant correlation between initial Total scores and Total scores obtained 2 weeks later.

A Pearson correlation was computed to estimate the relationship between the Total scores obtained on the initial administration and the Total scores obtained 2 weeks after the initial administration. The results of the analysis revealed a moderate positive relationship between the first administration scores ( $M = 21.95$ ,  $SD = 5.38$ ) and second administration scores ( $M = 23.18$ ,  $SD = 5.53$ ) and a statistically significant correlation [ $r(39) = .54$ ,  $p < .001$ ]. As a result of the analysis, the null hypothesis was rejected. Despite the null hypothesis being rejected, the coefficient did not meet established standards for test-retest reliability that sets a minimum coefficient of .80 (Gersten et al., 2011). Figure 2 shows the scatterplot of initial Structural-Symbolic Translation Fluency Total scores and scores obtained 2 weeks later.

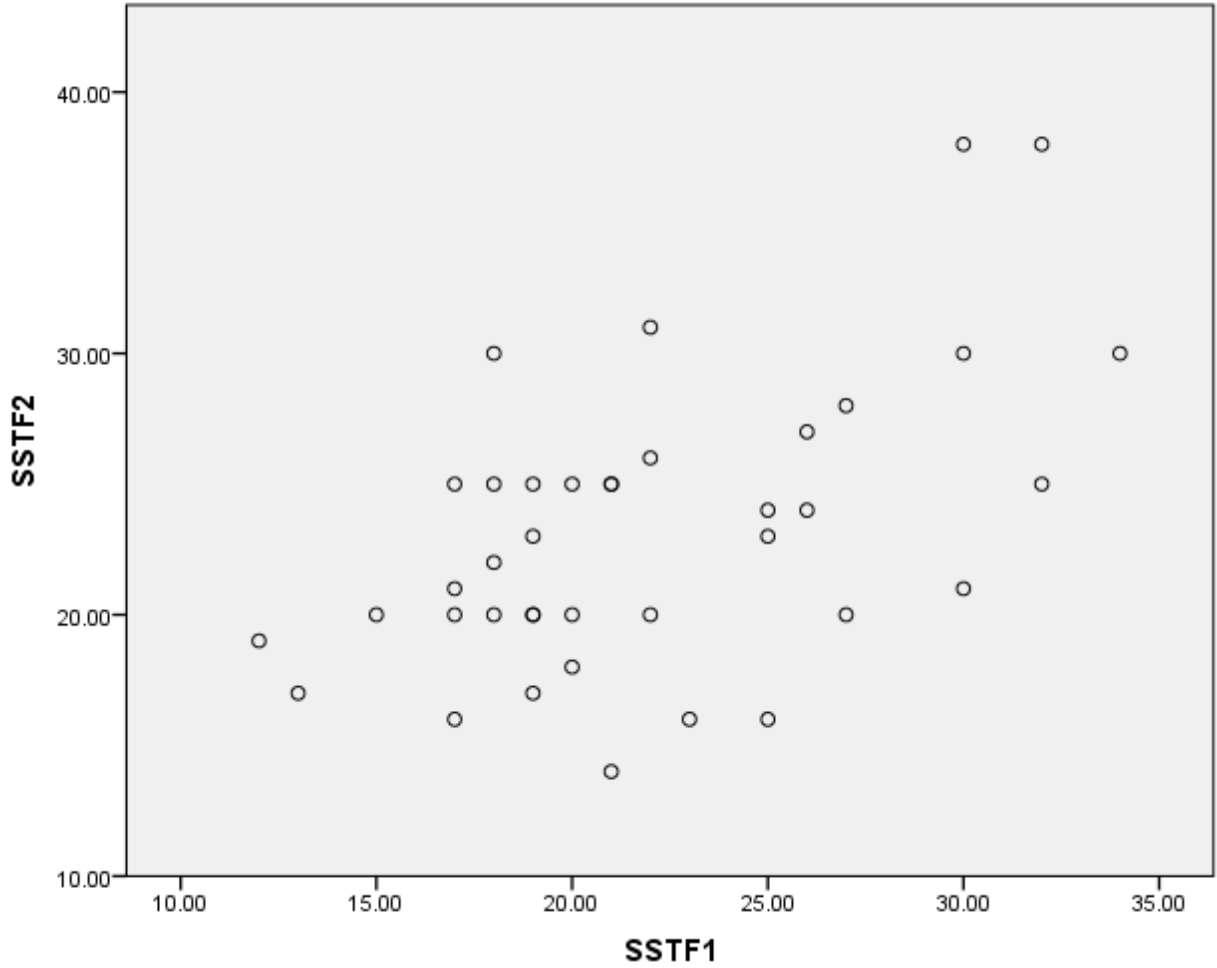


Figure 2: *Scatterplot of Initial Structural Symbolic Translation Fluency Total Scores and Total Scores Obtained 2 weeks Post Initial Administration*

### **Validity**

#### **Research Question 4**

Question 4: Does a panel of mathematical content experts agree on the alignment between the assessment items contained within the Structural-Symbolic Translation Fluency probe and the Common Core Standards for Operations and Algebraic Thinking in second grade?



H<sub>04</sub>: A panel of experts does not agree that there is alignment between the assessment items contained within the Structural-Symbolic Translation Fluency probe and the Common Core State Standards for Operations and Algebraic Thinking in second grade.

Eleven mathematics and psychometrics content experts responded to a survey to analyze the content validity of the Structural-Symbolic Translation Fluency Assessment. To answer this research question, content experts responded to the following survey item: *The items in the Structural-Symbolic Translation Fluency assessment are aligned to problem types second grade students should be familiar with based on the Common Core Standards-Mathematics.* The content experts responded via a Likert-type scale with the following anchors: Strongly Disagree (1), Disagree (2), Neither Agree or Disagree (3), Agree (4), or Strongly Agree (5). On this item 10 of the content experts selected “Strongly Agree” (91%) and one content expert selected “Agree” (9%). As a result of these responses the null hypotheses was rejected.

### **Research Question 5**

Question 5: Does a panel of mathematical content and psychometric experts agree on the accuracy of the computation situations, visual models, expressions, and equations utilized in the items contained within the Structural-Symbolic Translation Fluency probe?

H<sub>05</sub>: A panel of mathematical content experts does not agree on the accuracy of computation situations, visual models, expressions, and equations used in the items contained within the Structural-Symbolic Translation Fluency probe.

The 11 mathematics and psychometrics experts responded to 22 individual survey items to correspond to the 22 items on the Structural-Symbolic Translation Fluency probe. The item stated: *The word problem, correct part-part whole model, and correct equation or expression*

*were correctly aligned.* Experts were able to respond to the survey with “Yes” or “No”. When experts responded “No”, they were prompted to enter explanatory text. Of the 22 items, all of the content experts agreed on alignment of 14 items (64%). Nine content experts agreed on alignment of two items (9%), and eight content experts agreed on six of the items (27%). On all eight items that did not receive unanimous content expert agreement, the disagreement was in relation to the matching expressions or equations. Each of these eight items initially used an expression or equation demonstrating the reciprocal operation to solve the problem. The qualitative statements to “No” responses varied as to the commenter’s thoughts on the appropriateness of the use of reciprocal operations with second grade students. For example, one content expert expressed uncertainty by stating, “It depends on what data you are wanting to gain (interpretation or internalizing of the problem-using reciprocal operation). The equation selected does give you the correct answer, but, is this not an example of a missing addend?” Conversely, another commenter was more direct that the use of the reciprocal operation was not appropriate. This sentiment was evidenced in the statement, “This is  $13 - ? = 6$ . Please see Common Core Document Glossary Table 1.” Despite the Common Core Standards progression documents (Common Core Standards Writing Team, 2011) description of the use of a “solution equation” (often a reciprocal operation) as a skill to be acquired prior to second grade, the researcher elected to modify these items prior to data collection with the student sample. This decision was made based on the feedback from the expert panel and through discussion with second grade teachers who expressed concerns about students not perceiving reciprocal equations as “matching”. As a result, the expression or equation for each of the eight items was changed to reflect the opposite operation. Table 1 represents the frequency and percentage of “Yes” and “No” responses is below.

Table 1: *Frequency Table of Content Expert Agreement with Item Alignment for Story Problem, Structure, and Equation or Expression*

Item Number	No Responses	Yes Responses
1	0 (0%)	11 (100%)
2	0 (0%)	11 (100%)
3	0 (0%)	11 (100%)
4	0 (0%)	11 (100%)
5	3 (27%)	8 (73%)
6	3 (27%)	8 (73%)
7	2 (18%)	9 (82%)
8	0 (0%)	11 (100%)
9	0 (0%)	11 (100%)
10	2 (18%)	9 (82%)
11	0 (0%)	11 (100%)
12	0 (0%)	11 (100%)
13	3 (27%)	8 (73%)
14	0 (0%)	11 (100%)
15	0 (0%)	11 (100%)
16	0 (0%)	11 (100%)
17	3 (27%)	8 (73%)
18	0 (0%)	11 (100%)
19	0 (0%)	11 (100%)
20	3 (27%)	8 (73%)
21	3 (27%)	8 (73%)
22	0 (0%)	11 (100%)

## Research Question 6

Question 6: Does the Structural-Symbolic Translation Fluency Total score demonstrate concurrent convergent validity with the Number Knowledge Test?

H<sub>06</sub>: There is no significant correlation between the Structural-Symbolic Translation Fluency Total score and the Number Knowledge Test raw score.

A Pearson correlation was computed to estimate the relationship between the Structural-Symbolic Translation Fluency Total scores and the Number Knowledge Test raw scores. The results of the analysis revealed a moderate positive relationship between Structural-Symbolic Translation Fluency Total scores ( $M = 23.18$ ,  $SD = 5.53$ ) and Number Knowledge Test raw scores ( $M = 20.36$ ,  $SD = 4.29$ ) and a statistically significant correlation [ $r(39) = .56$ ,  $p < .01$ ]. As a result of the analysis, the null hypothesis was rejected. Despite the null hypothesis being rejected, the coefficient did not meet established standards for convergent validity that sets a minimum coefficient of .60 (Gersten et al., 2011). Figure 3 shows the scatterplot of Structural-Symbolic Translation Fluency Total scores and Number Knowledge Test raw scores.

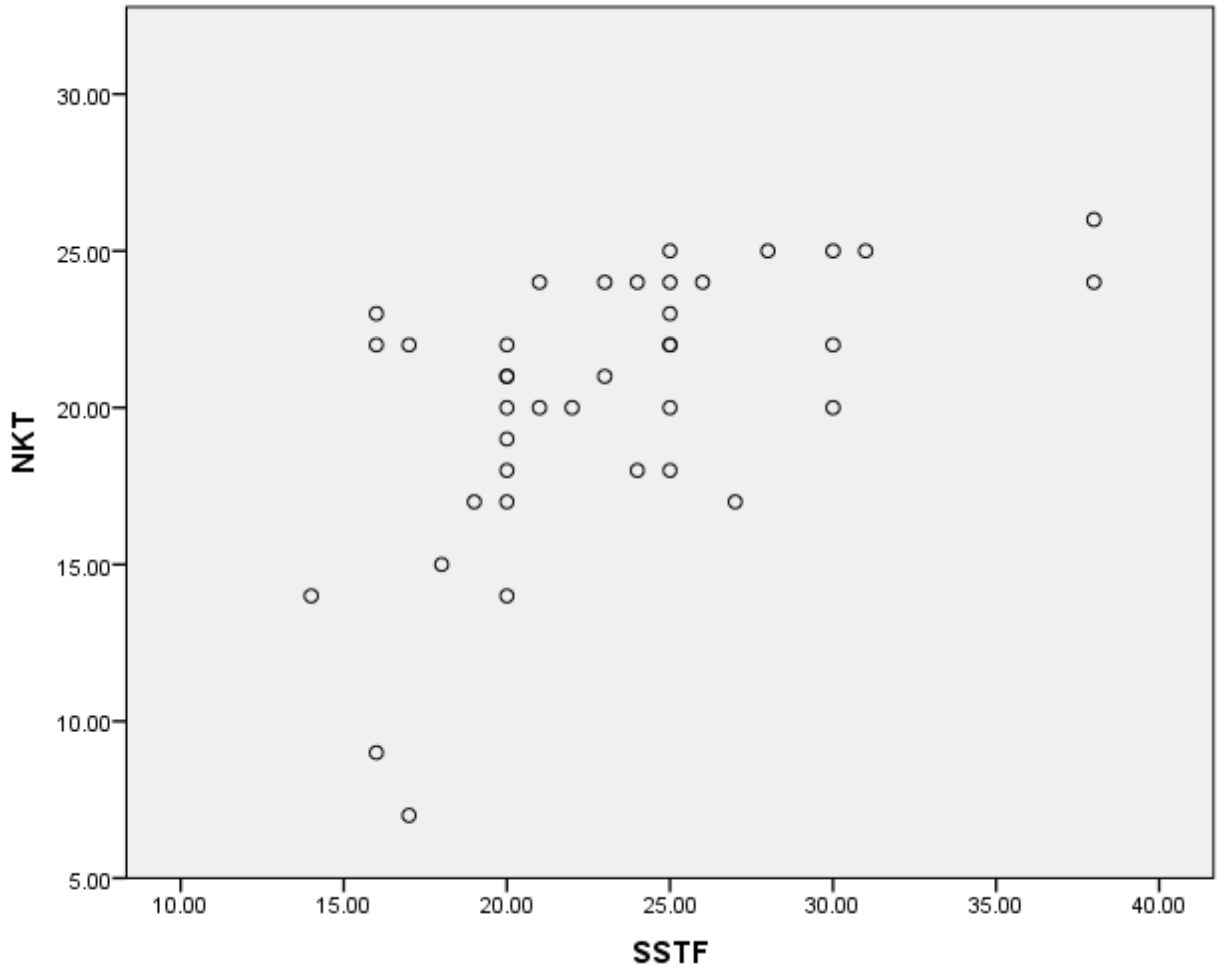


Figure 3: *Scatterplot of Structural Symbolic Translation Fluency Total Scores and Number Knowledge Test Raw Scores*

### Research Question 7

Question 7: Does the Structural-Symbolic Fluency Total score account for unique variance on the Number Knowledge Test when controlling for the Symbolic score?

$H_{07}$ : The Structural-Symbolic Fluency Total score does not account for unique variance on the Number Knowledge Test raw scores when controlling for the Symbolic score.

A hierarchical multiple regression analysis was conducted to evaluate whether the Structural-Symbolic Translation Fluency Total score accounts for unique variance on the Number Knowledge Test when controlling for the Symbolic score. The Structural-Symbolic Translation Fluency Total score did account for a significant proportion of unique variance on the Number Knowledge Test when controlling for the Symbolic score,  $R^2$  change = .10,  $F(1, 36) = 5.37$ ,  $p < .05$ . These results indicate that the Structural Symbolic Translation Fluency Total score accounted for 10% additional variance on Number Knowledge Test scores over and above that of the Symbolic score alone. Consequently, the Total score of the Structural-Symbolic Translation Fluency probe is a better predictor of Number Knowledge Test performance than the Symbolic Score in isolation. As a result the null hypothesis was rejected.

### **Research Question 8**

Question 8: Does the Structural-Symbolic Fluency Total score account for unique variance on the Number Knowledge Test when controlling for the Structural score?

H<sub>08</sub>: The Structural-Symbolic Fluency Total score does not account for unique variance on the Number Knowledge Test raw scores when controlling for the Structural score.

A hierarchical multiple regression analysis was conducted to evaluate whether the Structural-Symbolic Translation Fluency Total score accounts for unique variance on the Number Knowledge Test when controlling for the Structural score. The Structural-Symbolic Translation Fluency Total score did account for a significant proportion of unique variance on the Number Knowledge Test when controlling for the Structural score,  $R^2$  change = .18,  $F(1, 36) = 9.47$ ,  $p < .01$ . These results indicate that the Structural Symbolic Translation Fluency Total score accounted for 18% additional variance on Number Knowledge Test scores over and above that of

the Structural score alone. Consequently, the Total score of the Structural Symbolic Translation Fluency probe is a better predictor of Number Knowledge Test performance than the Structural Score in isolation. As a result the null hypothesis was rejected.

### **Research Question 9**

Question 9: Do teachers find the Structural-Symbolic Translation Fluency assessment useful for its intended purposes?

H<sub>09</sub>: Teachers do not find the Structural-Symbolic Translation Fluency assessment useful for its intended purposes.

Two teachers who administered the Structural-Symbolic Translation Fluency assessment responded to seven survey items concerning the usability of the assessment. The items seven items were as follows:

1. I fully understood the administration directions.
2. The students fully understood the administration directions.
3. I fully understood the scoring directions.
4. The Structural-Symbolic Translation Fluency assessment provided me with information that informs my teaching of mathematics.
5. The information garnered from the Structural-Symbolic Translation Fluency assessment was worth the time devoted to administered and scoring.
6. The Structural-Symbolic Translation Fluency assessment provided me with valuable information about my students' competence with translating language into mathematical operations.

7. I would recommend the use of the Structural-Symbolic Translation Fluency assessment to second grade teachers.

The teachers responded via a Likert-type scale with the following anchors: Strongly Disagree (1), Disagree (2), Neither Agree or Disagree (3), Agree (4), or Strongly Agree (5). On all seven of the items, both teachers Strongly Agreed. Through discussion with the teachers following the administration, two primary themes emerge. First, the teachers expressed that the scoring template provided valuable diagnostic information concerning patterns that emerged among problem types that received the most frequent errors. Notably, the teachers stated that comparison and start unknown problem types appeared to be the most challenging. Second, the teachers indicated that a potential barrier to the assessment's utility was the unique nature of measuring the translation process. Six students in the sample of 42 attempted to solve the problem, even though it was stated in the directions not to. The teachers hypothesized that their students had never taken a mathematics assessment in which they were not required to find a solution, and perhaps, that led to confusion as to the nature of the tasks required of them.

### **Additional Analysis**

Several additional descriptive and inferential statistics were analyzed to examine the psychometric properties of the assessment. First, descriptive statistics of the assessment were analyzed for the first and second administration. The analysis including the sample sizes, means, and standard deviations is depicted in Table 2.



Table 2: *Means and Standard Deviations for Structural-Symbolic Translation Fluency First and Second Administration*

Administration	<i>N</i>	<i>M</i>	<i>SD</i>
First Administration	39	21.94	5.38
Second Administration	39	23.17	5.52

As depicted in the table, the mean of the second administration was higher than the first, yet the variation of the scores was similar. In addition to descriptive statistics, histograms were generated to visually examine the distribution of scores on each assessment. The histograms were generated to ascertain whether scores on the assessment approximated a normal distribution. This was also included in the analysis because of concerns that an inordinate number of scores may be present within the theoretical distribution of guessing at random on each of the items. Because each item had a one in three chance of being correct if selected at random, the mean of the theoretical distribution of guessing at random would be 14.67. Broadly, the histograms confirmed that the majority of students obtained a score that was not due to random chance. The histograms of Structural Symbolic Translation Fluency Total scores at the first and second administrations are presented in Figures 4 and 5 below.

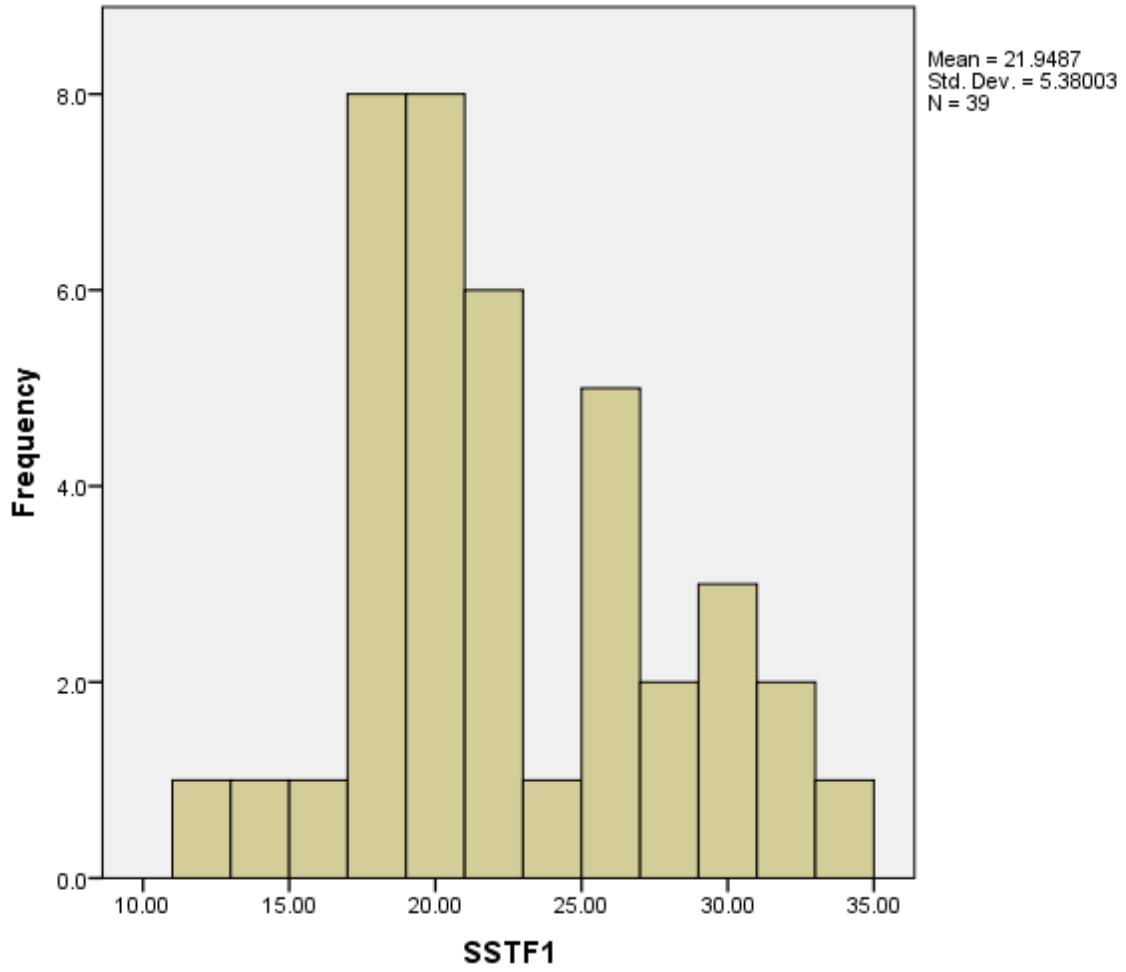


Figure 4: *Histogram of First Structural-Symbolic Translation Fluency Scores*

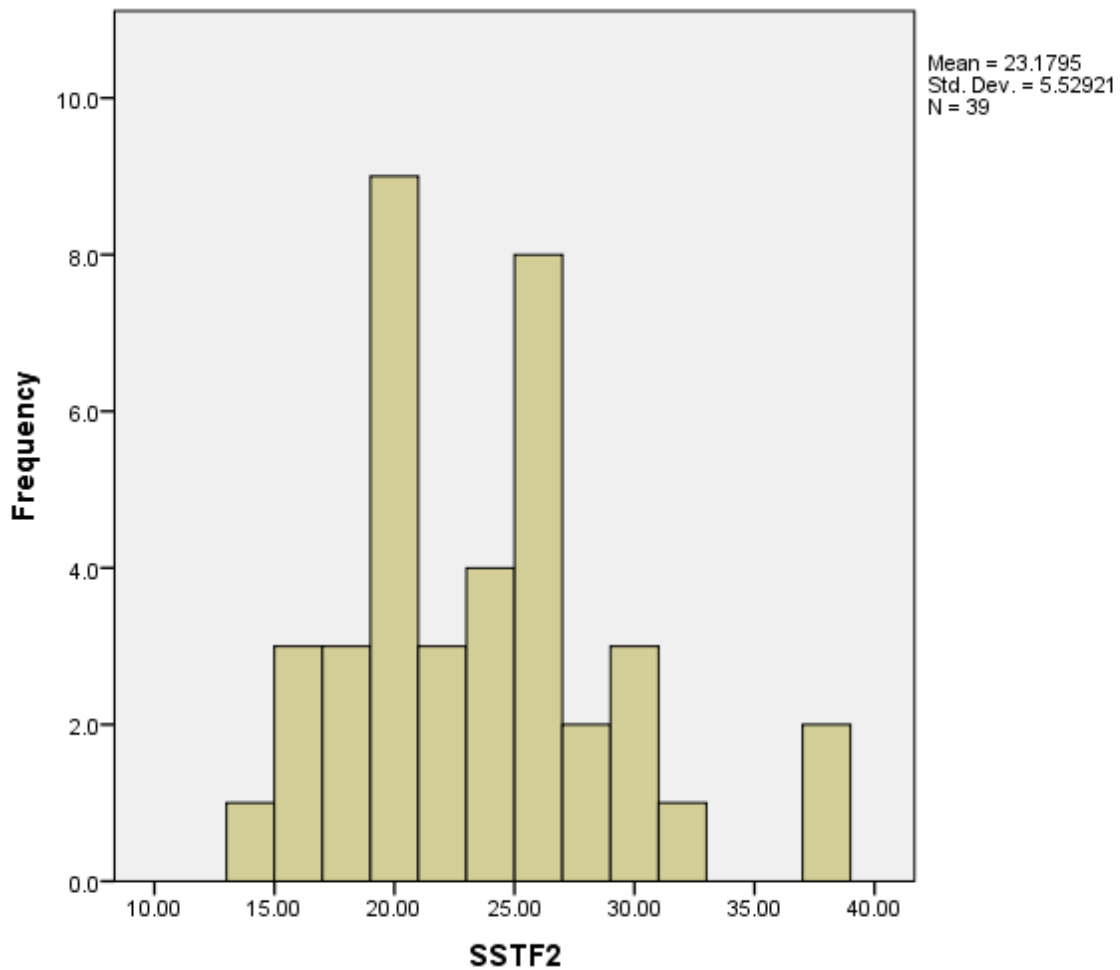


Figure 5: *Histogram of Second Structural-Symbolic Translation Fluency Scores*

Finally, a paired-samples *t* test was conducted to evaluate whether students scored significantly higher on either administration of Structural-Symbolic Translation Fluency. The results indicated no significant difference between scores obtained on the first ( $M = 21.94, SD = 5.38$ ) and second administrations ( $M = 23.17, SD = 5.52$ ),  $t(38) = -1.47, p > .05$ . The 95% confidence interval for the mean differences between the two administrations was -2.92 to .46.

## Summary

The purpose of this study was to develop and validate Structural-Symbolic Translation Fluency, a mathematics assessment for the measurement of the translation problem solving process proposed by Mayer (2002). Data from 11 mathematics and psychometrics experts and 42 second grade students were used to analyze nine research questions and nine null hypotheses. One research question was analyzed using a Spearman-Brown correlation, one research question was analyzed using a joint probability of agreement, two research questions were analyzed using Pearson correlations, two research questions were analyzed using hierarchical multiple regression, and three research questions were analyzed using frequencies obtained from surveys. Testing of the nine research questions revealed nine significant findings.

In regard to reliability a significant Spearman-Brown correlation was found in a split-half reliability analysis. Despite a significant correlation the coefficient did not meet widely agreed upon minimum standards for internal consistency. A joint probability of agreement analysis revealed high levels of inter-rater reliability that did meet widely agreed upon minimum standards for reliability. A significant Pearson correlation was found between the first administration of Structural-Symbolic Translation Fluency and a second administration 2 weeks following the initial administration. Despite a significant correlation the coefficient did not meet widely agreed upon minimum standards for test-retest reliability.

Concerning validity a panel of mathematics and psychometric experts agreed that the items on the assessment were adequately aligned to the Common Core State Standards for second grade mathematics. In addition, the panel unanimously agreed that the assessment demonstrated alignment of story problems, structures, and expression or equations for 14 of 22 items. For the eight items where content expert agreement was not unanimous, the researcher changed the items

prior to initial administration. On all eight items, the disagreement rested in the reviewers' thoughts on the appropriateness of including expressions and equations that used a reciprocal operation. A significant Pearson correlation was found between Structural-Symbolic Translation Fluency and the Number Knowledge Test. Despite a significant correlation the coefficient did not meet widely agreed upon minimum standards for concurrent convergent validity. Significant change in  $R^2$  was found as a result of hierarchical multiple regression, revealing that the Structural-Symbolic Translation Fluency Total score accounted for significant unique variance in Number Knowledge Test scores, over and above both the Structural and Symbolic scores in isolation.

Concerning usability two teachers who administered the assessment both strongly agreed that they understood the administration directions, that students understood the administration directions, they understood the scoring directions, that the assessment informed instruction, that the results were worth the time spent administering the assessment, that the assessment provided valuable information about students' problem solving, and that they would recommend the assessment to other teachers. Through discussion the teachers expressed that the scoring template provided valuable diagnostic information. In addition, the teachers hypothesized that their students may have demonstrated initial confusion with the assessment because it did not require them to generate an answer to the problems.

## CHAPTER 5

### SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

#### **Introduction**

The purpose of this quantitative study was to develop and validate Structural-Symbolic Translation Fluency. This assessment was developed with the intent to validly measure the mathematical problem solving process referred to as translation (Mayer, 2002). The assessment design was based on a literature review that revealed mathematical concept development occurring at the quantitative, structural, and symbolical levels (Dehaene, 2011; Faulkner, 2009; Griffin, 2004). Data were collected and analyzed from mathematical content experts and second grade students during the winter of 2016. For the purpose of this validation study, the characteristics of interest were reliability, validity, and usability.

#### **Summary of Findings**

Data from 11 mathematics and psychometrics content experts and 42 second grade students were collected to analyze nine research questions. Broadly, the research questions fell into three categories: reliability, validity, and usability. All nine of the research questions produced significant results. Despite the significant findings, the assessment failed to meet widely established minimum criteria for reliability and validity. This chapter summarizes these findings, hypothesizes why minimum standards were not met, and provides implications for practice and recommendations for future research.

## Reliability

Research questions 1, 2, and 3 addressed the reliability of the Structural-Symbolic Translation Fluency assessment. The characteristics of reliability that were examined included internal consistency, inter-rater reliability, and test-retest reliability. Generally, these analyses were conducted to determine whether the Structural-Symbolic Translation Fluency consistently measured some construct. Regarding internal consistency a split-half reliability analysis was conducted. The split-half estimate revealed a significant Pearson correlation as well as a Spearman Brown adjusted coefficient. The Spearman Brown adjustment was considered most appropriate, as it adjusts a Pearson correlation to estimate a test's reliability if the split-half test length was increased to the total length by adding parallel items (Allen & Yen, 1979). Despite the significant correlations, the adjusted coefficient did not meet established standards for internal consistency that sets a minimum coefficient of .80 (Gersten et al., 2011). As a result Structural-Symbolic Translation Fluency did not demonstrate evidence that it was consistently measuring a single construct. However, it is hypothesized that this minimum standard could be met if the sample size were to be increased in future research.

Structural Symbolic Translation fluency demonstrated a high degree of inter-rater reliability. A joint probability analysis revealed that independent raters (teachers and the researcher) agreed on the score of individual items more than 99% of the time. As a result, Structural-Symbolic Translation Fluency did meet established standards for inter-rater reliability that sets a minimum coefficient of .90 (Gersten et al., 2011). Therefore, Structural-Symbolic Translation Fluency did demonstrate evidence that it could be scored consistently across raters.

In terms of test-retest reliability a Pearson correlation obtained from an initial administration and an administration conducted 2 weeks later revealed a significant positive correlation.

Despite the significant correlation, the coefficient did not meet established standards for test-retest reliability that sets a minimum coefficient of .80 (Gersten et al., 2011). Consequently, Structural-Symbolic Translation Fluency did not demonstrate evidence that it was consistently measuring a construct over time. It is hypothesized that an improvement to the instrument could be made by increasing the number of sample items. Teachers reported that students demonstrated potential confusion with the assessment tasks because they were not required to provide an answer to the problem. As a result some of the variation between the scores from the first and second administration may be accounted for by this. While there were not significant differences between the first and second administration Total score means, the mean was higher for the second administration.

### **Validity**

To evaluate content validity a panel of mathematics and psychometrics experts completed a survey in which they were asked to indicate their level of agreement related to the alignment of Structural-Symbolic Translation Fluency items to the Common Core State Standards for second grade mathematics. Overall, the panel indicated high levels of agreement. Additionally, the panel unanimously agreed that Structural-Symbolic Translation Fluency demonstrated alignment of story problems, structures, and expression or equations for 14 of the 22 initial items. For the eight initial items on which content experts did not unanimously agree, the researcher changed the items to align to the experts' suggestions. On the eight items that were modified, the disagreement was related to the use of expressions and equations that used a reciprocal operation. As a result reciprocal operations were not used in the version that was administered to



students. Based on the analyzed feedback of the panel the modified version of Structural-Symbolic Translation Fluency was estimated to have adequate content validity.

Concurrent convergent validity was estimated through Pearson correlation with the Number Knowledge Test. The analysis revealed a significant correlation; however, the coefficient did not meet established standards for internal consistency that sets a minimum coefficient of .60 (Gersten et al., 2011). As a result, Structural-Symbolic Translation Fluency did not demonstrate that it adequately measured number sense or knowledge. It is hypothesized that the minimum coefficient could be achieved with a larger sample size and with adding an additional distractor for each structure and equation or expression. Based on visual examination of the scatter plots, the residuals from an estimated line of best fit were larger for lower Total scores that could have been obtained through random guessing. In addition, the two assessments are theoretically hypothesized to measure distinct but inter-related and mutually reinforcing, concepts. The Structural-Symbolic Translation Fluency assessment was designed to measure the process students engage in when translating the language of a mathematical word problem into a visual structure and a symbolic equation or expression. The Number Knowledge Test primarily measures aspects of a student's ability to visualize a number line, move flexibly on it, work within a base ten system, and apply flexibility in computation strategy usage.

To evaluate the utility of the different scores (Structural, Symbolic, and Total) produced by Structural-Symbolic Translation Fluency, significant change in  $R^2$  was found as a result of hierarchical multiple regression. This finding revealed that the Structural-Symbolic Translation Fluency Total score accounted for significant unique variance in Number Knowledge Test scores, over and above both the Structural and Symbolic scores in isolation. As a result, this

evaluation suggests that both the Structural and Symbolic scores should be included in any future iterations of the assessment.

### **Usability**

Two teachers both strongly agreed on features of usability. Most notable, they indicated that the assessment informed instructional decision making, that it was worth the time to administer, and that they would recommend its use to other teachers. During follow-up discussion, the teachers stated that Structural-Symbolic Translated Fluency yielded valuable diagnostic information concerning the computation situations that students were experiencing the most difficulty with. They indicated that these data could be subsequently used to improve provision of core mathematics instruction as well as provide targeted assistance to individual students. In addition, the teachers hypothesized that their students may have demonstrated initial confusion with the assessment because it did not require them to generate an answer to the problems. These comments led to the hypothesis that additional sample items may improve the psychometric features of the assessment.

### **Implications for Practice**

This study demonstrates the complexity and challenges associated with developing validated curriculum based measures of mathematical problem solving. Mathematical problem solving is a multifaceted endeavor and the cognitive processes associated with it do not always produce reliable behavioral responses in students. As a result, an informed, coherent, balanced, and efficient system of mathematics assessment should inform the daily instructional implementation

choices of teachers. The literature review and Chapter 2 and the results of this study yield the following implications for practice.

1. Teachers should incorporate multiple formative assessment techniques to inform daily instruction choices. Formative assessment should occur both formally and informally within the context of instruction. Qualitative interpretation of assessment data should not be sacrificed in favor of strictly quantitative interpretation. Standardized mathematics assessments should not constrain teaching to the skills represented on the test.
2. Increased mathematical content knowledge for teaching buttresses interpretation of assessment data. Teachers' deep conceptual understanding of mathematics, understanding of conceptual barriers students face, and having a flexible and adaptive teaching strategies all support the use of formative assessment data.
3. Situations in which students do not receive explicit feedback on assessments they complete should be limited.
4. Teachers should support students in developing an appreciation for mathematics that extends beyond simply finding a solution and producing an answer through the cognitive route of least resistance. The process of engaging in mathematical problem solving should be actively encouraged in the mathematics classroom. This includes explicit reinforcement of effort paired with high quality accessible instruction.
5. Teachers should assess and evaluate the cognitive processes students engage in when solving mathematics problems. Critically, teachers should ensure that students have access to mathematics instruction at the quantitative, structural, and symbolic levels.

6. The use of part-part-whole models should be systematically incorporated into instruction and scaled from number composition and decomposition to solving mathematical word problems.

### **Implications for Future Research**

Results from this research can be used to improve the psychometric properties of the Structural-Symbolic Translation Fluency instrument or inform development of other curriculum-based measures of mathematical problem solving. Suggestions for future research include:

1. There are several hypothesized modifications to the Structural-Symbolic Translation Fluency instrument that could improve the psychometric characteristics. Future research could examine the impact of increasing the number of sample items and increasing the number of distractor items.
2. Convergent concurrent validity of the Structural-Symbolic Translation Fluency should be evaluated with other measures of mathematical problem solving such as the *Woodcock Johnson IV* applied problems subtest.
3. Student feedback on the Structural-Symbolic Translation Fluency could be useful in improving the psychometric features of the assessment. Future research may include focus groups comprised of students who took the assessment.
4. Researcher should examine other assessment models that could be used to ascertain the translation process as applied to mathematical problem solving.

## Summary

The purpose of this study was to develop and validate an assessment of the mathematical problem solving process referred to as translation (Mayer, 2002). The assessment was designed to parallel mathematical concept development occurring at the quantitative, structural, and symbolical levels (Dehaene, 2011; Faulkner, 2009; Griffin, 2004). All of the research questions revealed significant findings, suggesting promise for future iterations of the Structural-Symbolic Translation Fluency assessment. Despite the significant findings several key characteristics of reliability and validity were sub-threshold relative to established criteria for test validation. Hypothesized modifications to improve the psychometric characteristics of the assessment could be the focus of future research.

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## APPENDICES

### Appendix A: IRB Approval



EAST TENNESSEE STATE  
UNIVERSITY

Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

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#### IRB APPROVAL – Initial Expedited Review

October 7, 2015

Matt Hoskins

**Re:** A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

**IRB#:** c0915.28sd

**ORSPA #:**

The following items were reviewed and approved by an expedited process:

- 107 xForm, PI CV, references, teacher ICD, parental permission, assent statement, interview questions, content reviewer letter ICD, content reviewer survey, teacher survey, Structural Sybmolic Translation Fluency Probe, Number Knowledge Test , Oral Reading Fluency probe, site permission letters and attestations

On **October 6, 2015**, a final approval was granted for a period not to exceed 12 months and will expire on **October 5, 2016**. The expedited approval of the study will be reported to the convened board on the next agenda.

The IRB has approved your study request to work with children as a vulnerable population. This approval was granted under category 1: this study presents no more than minimal risk to children because children can chose whether to participate and no grade is attached to the evaluation. The IRB determined parental permission is required under Category 2: The permission of one parent is sufficient because this study does not involve more than minimal risk. The permission of one parent in consistent with state law. Documentation of Parental Permission is required.

The IRB determined that the requirement for written documentation of assent is waived because all of the following are true: The research involves no more than minimal risk to the participants as all children that are in the classroom on the day the assessment is administered must be assented. The waiver will NOT adversely affect the rights and welfare of the participants. Children will be read an assent statement and told how to proceed if they do not want to participate. Students who do not wish to participate will turn in a blank piece of paper. The research could NOT practicably be carried out without the waiver. Whenever appropriate, the participants will be provided with additional pertinent information after participation.



Accredited Since December 2005

A waiver of requirement for written documentation of informed consent has been granted under category 45 CFR 46.117(c)(2) for .The research involves no more than minimal risk to the participants because it involves the completion of a survey via google and consent is usually not required for surveys/to answer questions. The investigator has provided a script of the consent discussion that meets the requirements for the consent process and includes all required and appropriate additional elements of disclosure.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Parental Permission (ver 8/10/15 SA 19/6/15), Teacher ICD (ver 8/21/15 SA 10/6/15), Child Assent (SA 10/6/15), Content Reviewer Letter (SA 10/6/15)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

**Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.**

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 ([www.etsu.edu/irb](http://www.etsu.edu/irb)). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,  
Stacey Williams, Chair  
ETSU Campus IRB

cc:

Appendix B: Superintendent Permission Stokes County

East Tennessee State University  
IRB – Office for the Protection of Human Research Subjects

Educational Research

I, Bonnie Mendenhall\*, grant permission to Matt Hoskins to  
(Institution Representative-Print Name) (Primary Investigator-Print Name)

conduct research for the study titled A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

at the following institutions:

Stokes County Schools \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

As superintendent, I attest that our educational institution has policies  
(Institution Representative Title)

developed in conjunction with parents regarding the following:

- The right of a parent of a student to inspect, upon the request of the parent, a survey created by a third party before the survey is administered or distributed by a school to a student.
- Any applicable procedures for granting a request by a parent for reasonable access to such survey within a reasonable period of time after the request is received.
- Arrangements to protect student privacy that are provided by the agency in the event of the administration or distribution of a survey to a student containing one or more of the following items (including the right of a parent of a student to inspect, upon the request of the parent, any survey containing one or more of such items):
  - Political affiliations or beliefs of the student or the student's parent.
  - Mental or psychological problems of the student or the student's family.
  - Sex behavior or attitudes.
  - Illegal, anti-social, self-harmful, or demeaning behavior.
  - Critical appraisals of other individuals with whom respondents have close family relationships. Legally recognized privileged or analogous relationships, such as those of lawyers, physicians, and ministers.
- Religion practices, affiliations, or beliefs of the student or the student's parent.
- Income (other than that required by law to determine eligibility for participation in a program or for receiving financial assistance under such program).
- The right of a parent of a student to inspect, upon the request of the parent, any instructional material used as part of the educational curriculum for the student.
- Any applicable procedures for granting a request by a parent for reasonable access to instructional material received.
- The administration of physical examinations or screenings that the school or agency may administer to a student.
- The collection, disclosure, or use of personal information collected from students for the purpose of marketing or for selling that information (or otherwise providing that information to others for that purpose), including arrangements to protect student privacy that are provided by the agency in the event of such collection, disclosure, or use.
- The right of a parent of a student to inspect, upon the request of the parent, any instrument used in the collection of personal information before the instrument is administered or distributed to a student.
- Any applicable procedures for granting a request by a parent for reasonable access to such instrument within a reasonable period of time after the request is received.

P.I. Matt C. Hoskins 9/16/15  
(Signature) (Date)

Institutional Rep. Bonnie Mendenhall 9-6-15\*  
(Signature) (Date)



Appendix C: Superintendent Permission Jackson County

**East Tennessee State University**  
**IRB – Office for the Protection of Human Research Subjects**

**Educational Research**

I, Dr. Michael Murray (Institution Representative Print Name), grant permission to Matt Hosens (Privacy Investigator Print Name) to

conduct research for the study titled A preliminary investigation into the reliability, validity, and usability of structural-symbolic translation fluency.  
at the following institutions:

Jackson County Schools

As Superintendent (Institution Representative Title), I attest that our educational institution has policies

developed in conjunction with parents regarding the following:

- The right of a parent of a student to inspect, upon the request of the parent, a survey created by a third party before the survey is administered or distributed by a school to a student.
- Any applicable procedures for granting a request by a parent for reasonable access to such survey within a reasonable period of time after the request is received.
- Arrangements to protect student privacy that are provided by the agency in the event of the administration or distribution of a survey to a student containing one or more of the following items (including the right of a parent of a student to inspect, upon the request of the parent, any survey containing one or more of such items):
  - > Political affiliations or beliefs of the student or the student's parent.
  - > Mental or psychological problems of the student or the student's family.
  - > Sex behavior or attitudes.
  - > Illegal, anti-social, self-harm/inflicting, or delinquent behavior.
  - > Critical appraisals of other individuals with whom respondents have close family relationships.
  - > Legally recognized privileged or analogous relationships, such as those of lawyers, physicians, and ministers.
- > Religious practices, affiliations, or beliefs of the student or the student's parent.
- > Income (other than that required by law to determine eligibility for participation in a program or for receiving financial assistance under such program).
- The right of a parent of a student to inspect, upon the request of the parent, any instructional material used as part of the educational curriculum for the student.
- Any applicable procedures for granting a request by a parent for reasonable access to instructional material received.
- The administration of physical examinations or screenings that the school or agency may administer to a student.
- The collection, disclosure, or use of personal information collected from students for the purpose of marketing or for selling that information (or otherwise providing that information to others for that purpose), including arrangements to protect student privacy that are provided by the agency in the event of such collection, disclosure, or use.
- The right of a parent of a student to inspect, upon the request of the parent, any instrument used in the collection of personal information before the instrument is administered or distributed to a student.
- Any applicable procedures for granting a request by a parent for reasonable access to such instrument within a reasonable period of time after the request is received.

P.I. Michael Murray (Signature) 8/27/15 (Date)

\* Institutional Rep. Matt Hosens (Signature) 8/28/15 (Date)



## Appendix D: Parental Permission

PRINCIPAL INVESTIGATOR: Matt C. Hoskins

TITLE OF PROJECT: A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

### Informed Consent Form (STUDENT VERSION)

This Informed Consent will explain the process of your child being a participant in a research study conducted on a mathematics assessment. It is important that you read this material carefully and then decide if you wish for your child to be a volunteer.

#### PURPOSE:

The purposes of this research study are as follows:

- To determine if an assessment of mathematics problem solving has the features to be successfully used by your child's teacher to guide instruction.
- If the assessment shows the features that it can be successfully used, this assessment could be utilized at the beginning of second grade to predict which students may need additional instructional supports for solving mathematical word problems

#### DURATION

The total time that your child will be participating in this research is approximately 20 minutes. This includes 8-10 minutes with the research mathematics assessment and 10-12 minutes with an additional math assessment. It is probable that your child would be taking the additional assessment as part of the typical assessment routine in his or her class. Approximately 45 second grade students in North Carolina will be participating in this research.

#### PROCEDURES

The procedures, which will involve your child as a research subject, include:

- Listening to the teacher recite a sample item
- Listening to math word problems being read aloud and circling corresponding pictures and equations that match the word problem

#### ALTERNATIVE PROCEDURES/TREATMENTS

There are no alternate procedures involved in this research study.

#### POSSIBLE RISKS/DISCOMFORTS

The possible risks and/or discomforts of your child's involvement include:

There are no known risks other than those ordinarily encountered in daily life or during the performance of routine mathematics assessments.

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Chair, IRB Coordinator

Page 1 of 3

Subject Initials \_\_\_\_\_

ETSU IRB

PRINCIPAL INVESTIGATOR: Matt C. Hoskins

TITLE OF PROJECT: A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

POSSIBLE BENEFITS

The possible benefits of your child's participation are:

As a result of your child participating in this research, your child's teacher may have a better understanding of his or her approach to solving mathematical word problems. As a result, this information may help your child's teacher customize instruction to best meet his or her needs.

VOLUNTARY PARTICIPATION

Participation in this research is voluntary. You may refuse for your child to participate. Your child can quit at any time. If your child quits or refuses to participate, the instruction to which he or she is entitled will not be affected. You may discontinue your child's participation by calling Matt Hoskins, whose phone number is 919-807-5997. You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about your child staying in the study.

In addition, if significant new findings during the course of the research may relate to your willingness to continue your child's participation are likely, the consent process must disclose this to you.

CONTACT FOR QUESTIONS

If you have any questions, you may call Matt Hoskins at 919-807-5997, or Dr. Eric Glover at 423-439-7566. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY

Every attempt will be made to see that your child's study results are kept confidential. All assessments will be coded and will not include any identifying information. A copy of the records from this study will be stored in a locked file cabinet for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU IRB, and the ETSU department of Educational Leadership and Policy Analysts have access to the study records.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your child's participation with the

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ETSU IRB

PRINCIPAL INVESTIGATOR: Matt C. Hoskins

TITLE OF PROJECT: A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

investigator. You freely and voluntarily choose for your child to be in this research project.

\_\_\_\_\_  
SIGNATURE OF PARTICIPANT'S PARENT DATE

\_\_\_\_\_  
PRINTED NAME OF PARTICIPANT'S PARENT DATE

\_\_\_\_\_  
SIGNATURE OF INVESTIGATOR DATE

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By *MS*  
Chair IRB Coordinator

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## Appendix E: Teacher Informed Consent

PRINCIPAL INVESTIGATOR: Matt C. Hoskins

TITLE OF PROJECT: A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

### Informed Consent Form (TEACHER VERSION)

This Informed Consent will explain about being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

#### PURPOSE:

The purposes of this research study are as follows:

- To determine if an assessment of mathematics problem solving has the features to be successfully used to guide instruction.
- If the assessment shows the features that it can be successfully used, this assessment could be utilized at the beginning of second grade to predict which students may need additional instructional supports for solving mathematical word problems

#### DURATION

An estimate of the time commitment devoted to this research are as follows:

- Receiving training on the scoring and administration of the Structural-Symbolic Translation Fluency assessment (45 minutes)
- Administration and scoring of the assessment to approximately 20 second grade students (45 minutes)
- Scoring another teacher's probes for inter-rater reliability (25 minutes)
- Coding the assessments, along with other data (Number Knowledge Test and DIBELS Oral Reading Fluency), to ensure identifying information is not available to the researcher (45 minutes)
- Completing a brief survey on the use of the instrument (45 minutes)
- Completing a brief interview on the use of the instrument (45 minutes)

This study is expected to be completed by December 19<sup>th</sup>, 2015.

#### ALTERNATIVE PROCEDURES/TREATMENTS

There are no alternate procedures involved in this research study.

#### POSSIBLE RISKS/DISCOMFORTS

The possible risks and/or discomforts of your involvement include:

There are no known risks other than those ordinarily encountered in daily life or during the administration of routine mathematics assessments.

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Classroom Coordinator

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PRINCIPAL INVESTIGATOR: Matt C. Hoskins

TITLE OF PROJECT: A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

#### POSSIBLE BENEFITS

The possible benefits of your participation are:

As a result of your participating in this research, you may have a better understanding of your students' approach to solving mathematical word problems. As a result, this information may help you customize instruction to best meet the needs of your students.

#### VOLUNTARY PARTICIPATION

Participation in this research is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, you will not be affected. You may discontinue your participation by calling Matt Hoskins, whose phone number is 919-807-5997. You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about your staying in the study.

In addition, if significant new findings during the course of the research may relate to your willingness to continue your child's participation are likely, the consent process must disclose this to you.

#### CONTACT FOR QUESTIONS

If you have any questions, you may call Matt Hoskins at 919-807-5997, or Dr. Eric Glover at 423-439-7566. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

#### CONFIDENTIALITY

Every attempt will be made to see that the study results are kept confidential. All assessments will be coded and will not include any identifying information. A copy of the records from this study will be stored in a locked file cabinet for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU IRB, and the ETSU department of Educational Leadership and Policy Analysis have access to the study records.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been

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Subject Initials \_\_\_\_\_

PRINCIPAL INVESTIGATOR: Matt C. Hoskins

TITLE OF PROJECT: A Preliminary Investigation into the Reliability, Validity, and Usability of Structural-Symbolic Translation Fluency

given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

---

SIGNATURE OF PARTICIPANT

DATE

---

PRINTED NAME OF PARTICIPANT

DATE

---

SIGNATURE OF INVESTIGATOR

DATE

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By *MCS*  
Chair ETSU IRB

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## Appendix F: Content Review Letter

Dear Content Reviewer:

My name is Matt Hoskins and I am a doctoral student in the Educational Leadership and Policy Analysis program at East Tennessee State University. I am currently conducting research for my dissertation. The purpose of my study is to find preliminary characteristics of reliability, validity, and usability in an assessment I created called Structural-Symbolic Translation Fluency.

Your participation to act as a reviewer of this assessment is due to your expertise in mathematics content and assessment. I invite you to complete a survey to describe your thoughts concerning:

- The alignment of the items to the Common Core State Standards of Mathematics within the Operations and Algebraic Thinking domain for second grade.
- The alignment of each word problem, the part-part-whole model, and the expression or equation.

The survey should take approximately 45 minutes to complete. Participation in the research study is completely voluntary. All responses will remain confidential and anonymous. No identifying information will be requested. I hope that you will consider participating in the study as it will help determine whether this assessment could be a useful tool for teachers in North Carolina.

Please complete the survey prior to ----- . Thank you for your time and consideration of this request. If you have any questions, please don't hesitate to call me at (336) 403-1412 or email me at [hoskinsm@goldmail.etsu.edu](mailto:hoskinsm@goldmail.etsu.edu). In addition, the chair for my research project is Dr. Eric Glover, a professor in the Educational Leadership and Policy Analysis program in the College of Education at ETSU.

Sincerely,

Matt C. Hoskins  
Doctoral Candidate  
East Tennessee State University  
Educational Leadership and Policy Analysis

## Appendix G: Student Assent Statement

### Assent Statement

"Over the next eight to ten minutes you will be answering some math questions. Your teacher will read some math story problems and you will circle pictures and equations that match the story problem. You will be doing this in order to test whether this is a good way to see how well you solve math problems. You will not get a grade on this and your participation is optional. If you decide you do not want to participate, you can decide to turn in a blank paper to your teacher."

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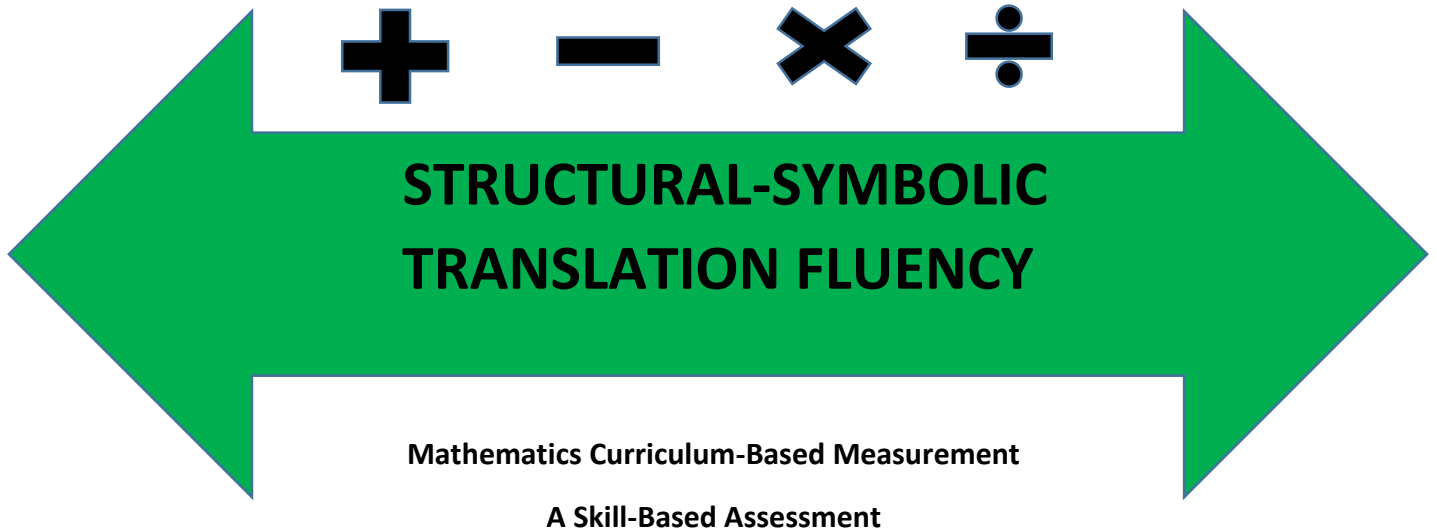
By Ms  
Chair IRB Coordinator

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**ETSU IRB**





## **OPERATIONS AND ALGEBRAIC THINKING**

### **SECOND GRADE: BEGINNING OF YEAR SCREENING STUDENT MATERIALS**

Name: \_\_\_\_\_

## SAMPLE ITEM

Courtney had 3 flowers and she gave 1 away. How many flowers does Courtney have now?

Circle One:

A

3	
1	?

B

?	
1	3

C

1	
3	?

Circle One:

A

$$1 + 3$$

B

$$3 - 1$$

C

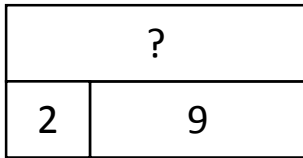
$$\boxed{?} - 1 = 3$$

1.

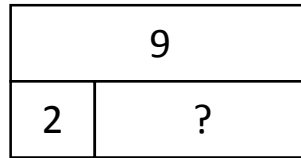
2 rabbits were in the grass. 9 more rabbits hopped there. Now how many rabbits are in the grass?

Circle One:

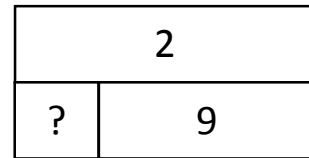
A



B



C



Circle One:

A

$$9 - 2$$

B

$$2 + 9$$

C

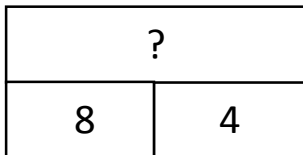
$$\boxed{?} + 2 = 9$$

2.

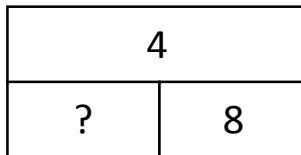
8 oranges were in the basket. Terry ate 4 oranges. Now how many oranges are in the basket?

Circle One:

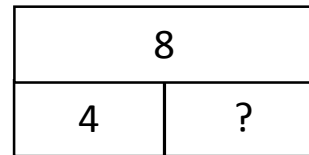
A



B



C



Circle One:

A

$$8 - 4$$

B

$$\boxed{?} - 4 = 8$$

C

$$8 + 4$$

3.

**Genna has 3 bananas. She also has 6 apples. How many pieces of fruit does she have?**

**Circle One:**

<b>A</b>	<b>B</b>	<b>C</b>												
<table border="1"><tr><td colspan="2">3</td></tr><tr><td>?</td><td>6</td></tr></table>	3		?	6	<table border="1"><tr><td colspan="2">6</td></tr><tr><td>3</td><td>?</td></tr></table>	6		3	?	<table border="1"><tr><td colspan="2">?</td></tr><tr><td>3</td><td>6</td></tr></table>	?		3	6
3														
?	6													
6														
3	?													
?														
3	6													

**Circle One:**

<b>A</b>	<b>B</b>	<b>C</b>
$6 - 3$	$3 + 6$	$\boxed{?} + 3 = 6$

4.

**Holden has 9 pennies. Jerry has 8 pennies. How many more pennies does Holden have?**

**Circle One:**

<b>A</b>	<b>B</b>	<b>C</b>												
<table border="1"><tr><td colspan="2">8</td></tr><tr><td>?</td><td>9</td></tr></table>	8		?	9	<table border="1"><tr><td colspan="2">?</td></tr><tr><td>9</td><td>8</td></tr></table>	?		9	8	<table border="1"><tr><td colspan="2">9</td></tr><tr><td>8</td><td>?</td></tr></table>	9		8	?
8														
?	9													
?														
9	8													
9														
8	?													

**Circle One:**

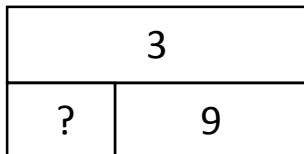
<b>A</b>	<b>B</b>	<b>C</b>
$9 + 8$	$8 + \boxed{?} = 9$	$8 - 9$

5.

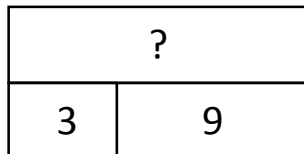
Malik had 3 stickers. His sister gave him some stickers. Then he had 9 stickers. How many stickers did his sister give him?

Circle One:

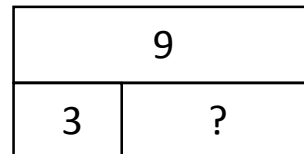
A



B



C



Circle One:

A

$$3 - 9$$

B

$$3 + 9$$

C

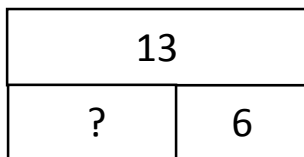
$$3 + \boxed{?} = 9$$

6.

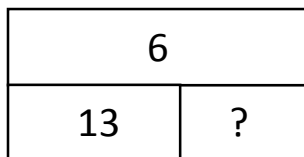
13 apples were in the tree. Some apples fell off. Now there are 6 apples in the tree. How many apples fell off?

Circle One:

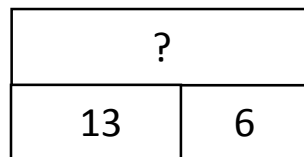
A



B



C



Circle One:

A

$$6 - 13$$

B

$$13 - \boxed{?} = 6$$

C

$$13 + 6$$

7.

7 plates were on the table. 3 are red and the rest are green. How many are green?

**Circle One:**

<b>A</b>	<b>B</b>	<b>C</b>												
<table border="1"><tr><td colspan="2">?</td></tr><tr><td>3</td><td>7</td></tr></table>	?		3	7	<table border="1"><tr><td colspan="2">7</td></tr><tr><td>3</td><td>?</td></tr></table>	7		3	?	<table border="1"><tr><td colspan="2">3</td></tr><tr><td>?</td><td>7</td></tr></table>	3		?	7
?														
3	7													
7														
3	?													
3														
?	7													

**Circle One:**

<b>A</b>	<b>B</b>	<b>C</b>
$7 - 3$	$\boxed{?} - 3 = 7$	$7 + 3$

8.

Tom has 7 fewer soccer goals than Craig. Tom has 2 goals. How many goals does Craig have?

**Circle One:**

<b>A</b>	<b>B</b>	<b>C</b>												
<table border="1"><tr><td colspan="2">?</td></tr><tr><td>2</td><td>7</td></tr></table>	?		2	7	<table border="1"><tr><td colspan="2">7</td></tr><tr><td>2</td><td>?</td></tr></table>	7		2	?	<table border="1"><tr><td colspan="2">2</td></tr><tr><td>?</td><td>7</td></tr></table>	2		?	7
?														
2	7													
7														
2	?													
2														
?	7													

**Circle One:**

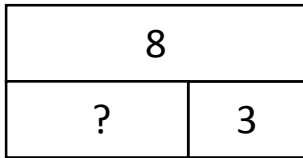
<b>A</b>	<b>B</b>	<b>C</b>
$\boxed{?} + 2 = 7$	$2 + 7$	$7 - 2$

9.

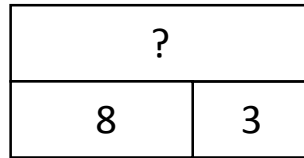
There were some ducks in the pond. 3 more ducks landed in the pond. Then there were 8 ducks in the pond. How many ducks were in the pond to start?

Circle One:

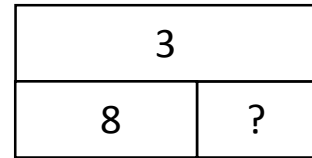
A



B



C



Circle One:

A

$$8 + 3$$

B

$$\boxed{?} + 3 = 8$$

C

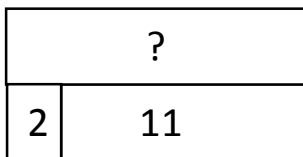
$$3 - 8$$

10.

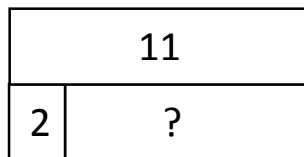
Steven had some stickers. He lost 2. Then he had 11 stickers. How many did he start with?

Circle One:

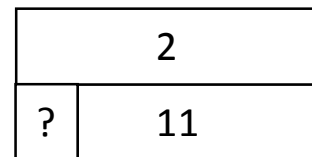
A



B



C



Circle One:

A

$$11 - 2$$

B

$$2 - 11$$

C

$$\boxed{?} - 2 = 11$$

11.

Julio has 7 more lollipops than Terry. Julio has 11 lollipops. How many lollipops does Terry have?

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">7</td></tr> <tr><td style="text-align: center;">11</td><td style="text-align: center;">?</td></tr> </table>	7		11	?	<p><b>B</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">11</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">7</td></tr> </table>	11		?	7	<p><b>C</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">7</td><td style="text-align: center;">11</td></tr> </table>	?		7	11
7														
11	?													
11														
?	7													
?														
7	11													

**Circle One:**

<p><b>A</b></p> <p style="font-size: 2em;"><b>11 + 7</b></p>	<p><b>B</b></p> <p style="font-size: 2em;"><b><span style="border: 1px solid black; padding: 2px;">?</span> + 7 = 11</b></p>	<p><b>C</b></p> <p style="font-size: 2em;"><b>7 - 11</b></p>
--	--	--

12.

Jared had 6 toy cars. Then his father gave him 7 more. How many toys cars did he have all together?

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">6</td><td style="text-align: center;">7</td></tr> </table>	?		6	7	<p><b>B</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">7</td></tr> <tr><td style="text-align: center;">6</td><td style="text-align: center;">?</td></tr> </table>	7		6	?	<p><b>C</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">6</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">7</td></tr> </table>	6		?	7
?														
6	7													
7														
6	?													
6														
?	7													

**Circle One:**

<p><b>A</b></p> <p style="font-size: 2em;"><b>7 - 6</b></p>	<p><b>B</b></p> <p style="font-size: 2em;"><b>6 + 7</b></p>	<p><b>C</b></p> <p style="font-size: 2em;"><b>6 + <span style="border: 1px solid black; padding: 2px;">?</span> = 7</b></p>
---	---	---



13.

**11 monkeys were in a tree. 7 monkeys left. Now how many monkeys were in the tree?**

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">11</td><td style="text-align: center;">7</td></tr> </table>	?		11	7	<p><b>B</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">11</td></tr> <tr><td style="text-align: center;">7</td><td style="text-align: center;">?</td></tr> </table>	11		7	?	<p><b>C</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">7</td></tr> <tr><td style="text-align: center;">11</td><td style="text-align: center;">?</td></tr> </table>	7		11	?
?														
11	7													
11														
7	?													
7														
11	?													

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td style="text-align: center;">?</td></tr> </table> <p><b>- 7 = 11</b></p>	?	<p><b>11 - 7</b></p>	<p><b>7 + 11</b></p>
?			

14.

**Stella has 3 bracelets. She also has 9 necklaces. How many pieces of jewelry does she have?**

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">3</td></tr> <tr><td style="text-align: center;">9</td><td style="text-align: center;">?</td></tr> </table>	3		9	?	<p><b>B</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">9</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">8</td></tr> </table>	9		?	8	<p><b>C</b></p> <table border="1" style="margin: auto; border-collapse: collapse;"> <tr><td colspan="2" style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">3</td><td style="text-align: center;">9</td></tr> </table>	?		3	9
3														
9	?													
9														
?	8													
?														
3	9													

**Circle One:**

<p><b>3 + 9</b></p>	<p><b>9 - 3</b></p>	<p><table border="1" style="display: inline-table; border-collapse: collapse;"><tr><td style="text-align: center;">?</td></tr></table> <b>+ 3 = 9</b></p>	?
?			

15.

Julie read 12 books and Sarah read 3 books. How many fewer books did Sarah read?

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto;"> <tr><td colspan="2" style="text-align: center;">3</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">12</td></tr> </table>	3		?	12	<p><b>B</b></p> <table border="1" style="margin: auto;"> <tr><td colspan="2" style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">3</td><td style="text-align: center;">12</td></tr> </table>	?		3	12	<p><b>C</b></p> <table border="1" style="margin: auto;"> <tr><td colspan="2" style="text-align: center;">12</td></tr> <tr><td style="text-align: center;">3</td><td style="text-align: center;">?</td></tr> </table>	12		3	?
3														
?	12													
?														
3	12													
12														
3	?													

**Circle One:**

<p><b>A</b></p> $\boxed{?} - 12 = 3$	<p><b>B</b></p> $12 + 3$	<p><b>C</b></p> $12 - 3$
--------------------------------------	--------------------------	--------------------------

16.

6 frogs were on a log. Some more frogs jumped on the log. Then there were 12 frogs. How many frogs jumped on the log?

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto;"> <tr><td colspan="2" style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">6</td><td style="text-align: center;">12</td></tr> </table>	?		6	12	<p><b>B</b></p> <table border="1" style="margin: auto;"> <tr><td colspan="2" style="text-align: center;">6</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">12</td></tr> </table>	6		?	12	<p><b>C</b></p> <table border="1" style="margin: auto;"> <tr><td colspan="2" style="text-align: center;">12</td></tr> <tr><td style="text-align: center;">6</td><td style="text-align: center;">?</td></tr> </table>	12		6	?
?														
6	12													
6														
?	12													
12														
6	?													

**Circle One:**

<p><b>A</b></p> $6 + \boxed{?} = 12$	<p><b>B</b></p> $6 + 12$	<p><b>C</b></p> $6 - 12$
--------------------------------------	--------------------------	--------------------------

17.

7 people were watching the movie. Some people left. Then there were 2 people watching the movie. How many people left?

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto;"> <tr><td style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">7</td><td style="text-align: center;">2</td></tr> </table>	?	7	2	<p><b>B</b></p> <table border="1" style="margin: auto;"> <tr><td style="text-align: center;">7</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">2</td></tr> </table>	7	?	2	<p><b>C</b></p> <table border="1" style="margin: auto;"> <tr><td style="text-align: center;">2</td></tr> <tr><td style="text-align: center;">7</td><td style="text-align: center;">?</td></tr> </table>	2	7	?
?											
7	2										
7											
?	2										
2											
7	?										

**Circle One:**

<p><b>A</b></p> <p style="font-size: 2em;"><math>7 + 2</math></p>	<p><b>B</b></p> <p style="font-size: 2em;"><math>2 - 7</math></p>	<p><b>C</b></p> <p style="font-size: 2em;"><math>7 - \boxed{?} = 2</math></p>
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18.

9 toys are in the room. 6 are cars and the rest are dolls. How many are dolls?

**Circle One:**

<p><b>A</b></p> <table border="1" style="margin: auto;"> <tr><td style="text-align: center;">9</td></tr> <tr><td style="text-align: center;">6</td><td style="text-align: center;">?</td></tr> </table>	9	6	?	<p><b>B</b></p> <table border="1" style="margin: auto;"> <tr><td style="text-align: center;">6</td></tr> <tr><td style="text-align: center;">?</td><td style="text-align: center;">9</td></tr> </table>	6	?	9	<p><b>C</b></p> <table border="1" style="margin: auto;"> <tr><td style="text-align: center;">?</td></tr> <tr><td style="text-align: center;">9</td><td style="text-align: center;">6</td></tr> </table>	?	9	6
9											
6	?										
6											
?	9										
?											
9	6										

**Circle One:**

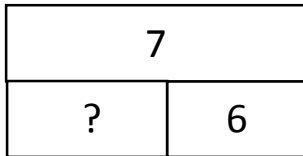
<p><b>A</b></p> <p style="font-size: 2em;"><math>9 + 6</math></p>	<p><b>B</b></p> <p style="font-size: 2em;"><math>6 + \boxed{?} = 9</math></p>	<p><b>C</b></p> <p style="font-size: 2em;"><math>6 - 9</math></p>
---	---	---

19.

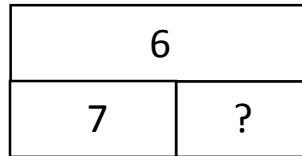
Stacy has 6 more marbles than Aliyah. Aliyah has 7 marbles. How many marbles does Stacy have?

Circle One:

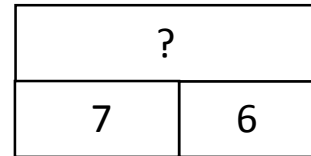
A



B



C



Circle One:

A

$$6 + \boxed{?} = 7$$

B

$$7 + 6$$

C

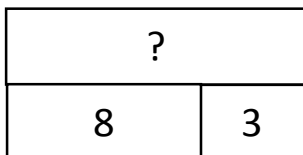
$$6 - 7$$

20.

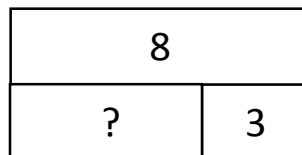
John had some pennies. His mom gave him 3 more pennies. Then he had 8 pennies. How many pennies did he start with?

Circle One:

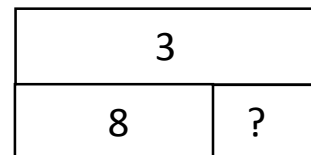
A



B



C



Circle One:

A

$$8 + 3$$

B

$$\boxed{?} + 3 = 8$$

C

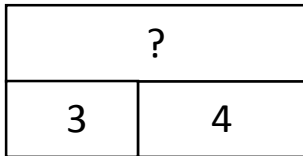
$$3 - 8$$

21.

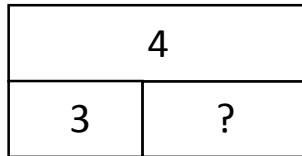
Makayla had some pieces of gum. She gave 3 to her friend. Then she had 4 pieces of gum. How many pieces of gum did she start with?

Circle One:

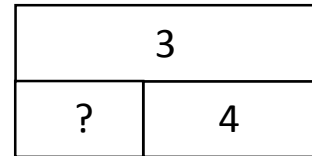
A



B



C



Circle One:

A

$$4 - 3$$

B

$$3 - 4$$

C

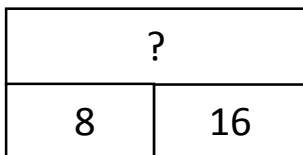
$$\boxed{?} - 3 = 4$$

22.

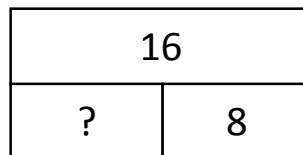
Juan has played 8 fewer video games than Joe. Joe has played 16 video games. How many video games has Juan played?

Circle One:

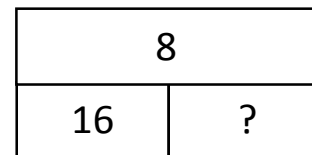
A



B



C



Circle One:

A

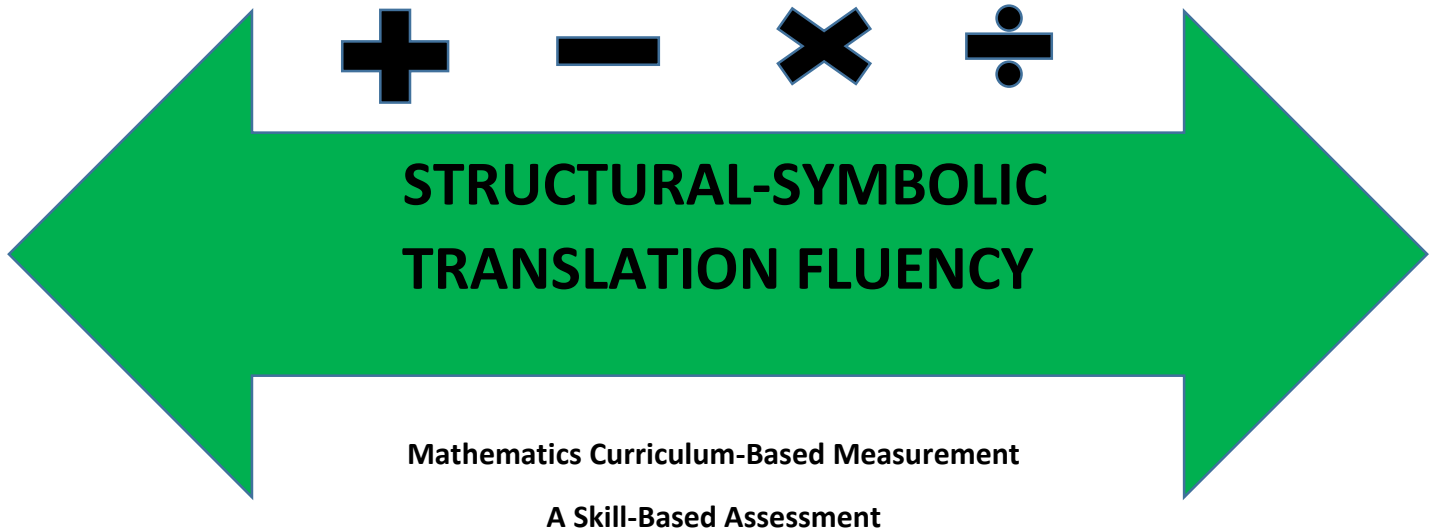
$$8 + 16$$

B

$$16 - 8$$

C

$$\boxed{?} - 8 = 16$$



## **OPERATIONS AND ALGEBRAIC THINKING**

### **SECOND GRADE: BEGINNING OF YEAR SCREENING TEACHER MATERIALS**

## BASIC ADMINISTRATION DIRECTIONS:

Structural-Symbolic Translation Fluency can be administered to individual students or an entire class. *To obtain meaningful scores, it is critical that administration directions are followed exactly.*

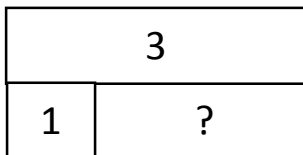
- Ensure all students have a sharpened pencil.
- Distribute the student materials to students face down on the desk.
- Say: **“Please turn your papers over. We will be working on some math problems. I will read each problem aloud. When I am done reading, I want you to circle the correct answer for a picture and an expression or equation that matches the story. You will have fifteen seconds to circle the picture and the expression or equation. At the end of fifteen seconds, I will say stop and you will put your pencil down as I read the next problem. Only work the problems we are on as a group, do not work ahead. Let’s try a problem to practice. Please turn the page.”**
- If a student asks for help or for a problem to be repeated say, **“Just do the best you can.”**

Read the following story problem aloud. Immediately after reading the problem, start your stop watch. At the end of 15 seconds say, **“Stop, please put your pencil down.”**

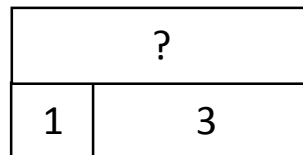
**Courtney had 3 flowers and she gave 1 away. How many flowers does Courtney have now?**

**Circle One:**

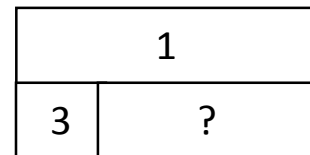
**A**



**B**



**C**



**Circle One:**

**A**

$$1 + 3$$

**B**

$$3 - 1$$

**C**

$$\boxed{?} - 1 = 3$$

Say, **“The correct answer for the picture is A. The correct answer for the expression or equation is B. You should have circled A for the picture and B for the expression or equation. If you did not, change your answers now.”**

Say, "Now we will be doing some more problems. Remember, you will have 15 seconds to circle a picture and an expression or equation that matches the story. When I say stop, please put your pencils down."

<p>1. Two rabbits were in the grass. Nine more rabbits hopped there. Now how many rabbits are in the grass?</p>
<p>2. Eight oranges were in the basket. Terry ate four oranges. Now how many oranges are in the basket?</p>
<p>3. Genna has three bananas. She also has six apples. How many pieces of fruit does she have?</p>
<p>4. Holden has nine pennies. Jerry has eight pennies. How many more pennies does Holden have?</p>
<p>5. Malik had three stickers. His sister gave him some stickers. Then he had nine stickers. How many stickers did his sister give him?</p>
<p>6. Thirteen apples were in the tree. Some apples fell off. Now there are six apples in the tree. How many apples fell off?</p>
<p>7. Seven plates were on the table. Three are red and the rest are green. How many are green?</p>
<p>8. Tom has seven fewer soccer goals than Craig. Tom has two goals. How many goals does Craig have?</p>
<p>9. There were some ducks in the pond. Three more ducks landed in the pond. Then there were eight ducks in the pond. How many ducks were in the pond to start?</p>



**10. Steven had some stickers. He lost two. Then he had eleven stickers. How many did he start with?**

**11. Julio has seven more lollipops than Terry. Julio has eleven lollipops. How many lollipops does Terry have?**

**12. Jared had six toy cars. Then his father gave him seven more. How many toy cars did he have all together?**

**13. Eleven monkeys were in a tree. Seven monkeys left. Now how many monkeys were in the tree?**

**14. Stella has three bracelets. She also has nine necklaces. How many pieces of jewelry does she have?**

**15. Julie read twelve books and Sarah read three books. How many fewer books did Sarah read?**

**16. Six frogs were on a log. Some more frogs jumped on the log. Then there were twelve frogs. How many frogs jumped on the log?**

**17. Seven people were watching the movie. Some people left. Then there were two people watching the movie. How many people left?**

**18. Nine toys are in the room. Six are cars and the rest are dolls. How many are dolls?**

19. Stacy has six more marbles than Aliyah. Aliyah has seven marbles. How many marbles does Stacy have?

20. John had some pennies. His mom gave him three more pennies. Then he had eight pennies. How many pennies did he start with?

21. Makayla had some pieces of gum. She gave three to her friend. Then she had four pieces of gum. How many pieces of gum did she start with?

22. Juan has played eight fewer video games than Joe. Joe has played sixteen video games. How many video games has Juan played?

### SCORING DIRECTIONS

Use the **Structural-Symbolic Translation Fluency Scoring Template** and **Scoring Protocol** for the scoring process.

The **Structural-Symbolic Translation Fluency Scoring Template** contains the correct responses.

The **Structural-Symbolic Translation Fluency Scoring Protocol** is used to determine the student's scores. To score the probe, use the **Structural-Symbolic Translation Fluency Scoring Protocol** to score one point for each structure circled correctly and one point for each expression/equation circled correctly. When finished, add the Structure column to obtain the **Structural Score**. Add the Expression/Equation column to obtain the **Symbolic Score**. Add the Structural and Symbolic scores to obtain the **Total Score**.

Appendix J: Structural-Symbolic Translation Fluency Scoring Protocol

Code \_\_\_\_\_

Word Problem	Problem Type	Structure (1 or 0)	Expression/Equation (1 or 0)
1. 2 rabbits were in the grass. 9 more rabbits hopped there. Now how many rabbits were in the grass?	Add to- Result Unknown		
2. 8 oranges were in the basket. Terry ate 4 oranges. Now how many oranges are in the basket?	Take from- Result Unknown		
3. Genna has 3 bananas. She also has 6 apples. How many pieces of fruit does she have?	Put Together/ Take Apart- Total Unknown		
4. Holden has 9 pennies. Jerry has 8 pennies. How many more pennies does Holden have?	Compare - Difference Unknown (more version)		
5. Malik has 3 stickers. His sister gave him some stickers. Then he had 9 stickers. How many stickers did his sister give him?	Add to- Change Unknown		
6. 13 apples were in the tree. Some apples fell off. Now there are 6 apples in the tree. How many apples fell off?	Take from- Change Unknown		
7. 7 plates were on the table. 3 are red and the rest are green. How many are green?	Put Together/ Take Apart- Addend Unknown		
8. Tom has 7 fewer soccer goals than Craig. Tom has 2 goals. How many goals does Craig have?	Compare- Bigger Unknown (fewer version)		

Word Problem	Problem Type	Structure (1 or 0)	Expression/ Equation (1 or 0)
9. There were some ducks in the pond. 3 more ducks landed in the pond. Then there were 8 ducks in the pond. How many ducks were in the pond to start?	Add to- Start Unknown		
10. Steven had some stickers. He lost 2. Then he had 11 stickers. How many did he start with?	Take From- Start Unknown		
11. Julio has 7 more lollipops than Terry. Julio has 11 lollipops. How many lollipops does Terry have?	Compare- Smaller Unknown (more version)		
12. Jared had 6 toy cars. Then his father gave him 7 more. How many toys cars did he have all together?	Add to- Result Unknown		
13. 11 monkeys were in a tree. 7 monkeys left. Now how many monkeys were in the tree?	Take from- Result Unknown		
14. Stella has 3 bracelets. She also has 9 necklaces. How many pieces of jewelry does she have?	Put Together/Take Apart- Total Unknown		
15. Julie read 12 books and Sarah read 3 books. How many fewer books did Sarah read?	Compare - Difference Unknown (fewer version)		
16. 6 frogs were on a log. Some more frogs jumped on the log. Then there were 12 frogs. How many frogs jumped on the log?	Add to- Change Unknown		

Word Problem	Problem Type	Structure (1 or 0)	Expression/Equation (1 or 0)
17. 7 people were watching the movie. Some people left. Then there were 2 people watching the movie. How many people left?	Take from- Change Unknown		
18. 9 toys are in the room. 6 are cars and the rest are dolls. How many are dolls?	Put Together/Take Apart- Addend Unknown		
19. Stacy has 6 more marbles than Aliyah. Aliyah has 7 marbles. How many marbles does Stacy have?	Compare- Bigger Unknown (more version)		
20. John had some pennies. His mom gave him 3 more pennies. Then he had 8 pennies. How many pennies did he start with?	Add to- Start Unknown		
21. Makayla had some pieces of gum. She gave 3 to her friend. Then she had 4 pieces of gum. How many pieces of gum did she start with?	Take From- Start Unknown		
22. Juan has played 8 fewer video games than Joe. Joe has played 16 video games. How many video games has Juan played?	Compare- Smaller Unknown (fewer version)		
		<b>Structural Score</b>	<b>Symbolic Score</b>
		<b>+</b>	
		<b>TOTAL =</b>	

VITA

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East Tennessee State University, Johnson City, TN  
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School Psychologist, 2007 - 2011  
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