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MATCHING EDUCATIONAL INTERVENTIONS TO BEHAVIORAL
PHENOTYPES: SPATIAL-TEMPORAL MATH AS A MATHEMATICS
ACHIEVEMENT INTERVENTION FOR
STUDENTS WITH AUTISM SPECTRUM DISORDERS

A Dissertation

Presented to

the Faculty of the Morgridge College of Education

University of Denver

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

by

Erin S. Grell

August 2012

Advisor: Karen Riley

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Title: MATCHING EDUCATIONAL INTERVENTIONS TO BEHAVIORAL PHENOTYPES: SPATIAL-TEMPORAL MATH AS A MATHEMATICS ACHIEVEMENT INTERVENTION FOR STUDENTS WITH AUTISM SPECTRUM DISORDERS

Advisor: Karen Riley

Degree Date: August, 2012

Abstract

Autism Spectrum Disorders (ASDs), a rapidly growing group of neurodevelopmental disorders, affect nearly all aspects of development. The knowledge base of ASDs has increased significantly over the past half century due to translational research models (Rutter, 1999). Basic science and applied clinical work have informed research in a bi-directional manner. Through these models, much is now known about the language, behavioral, and cognitive difficulties associated with ASDs. However, autism research would benefit from further delineation of the differences between ASD types through the development of behavioral phenotypes. Behavioral phenotypes are expressions of particular aspects of disorders that may aid in further differentiation of subtypes of disorders (Hoddapp & Dykens, 1997).

In particular, little is known about math achievement and math interventions for students with ASDs. Despite federal mandates (IDEIA, 2004; NCLB, 2001) that strive to ensure that students with disabilities are held to the same high academic standards as other students, the research base on math interventions for students with ASDs is inadequate (Minshey, Sweeny, Bauman, & Webb, 2005). ST Math, a computerized, pictorially-based math intervention contains many features that support the strengths of students with ASDs.

To better understand the effect ST Math might have on the math achievement of students with ASDs, 10 students from a private school in Denver, Colorado participated in the ST Math program over the course of one school year. Individual behavioral phenotypes were developed for these students, based on information obtained from Individual Education Plans (IEPs). A combination of comparative and single-case analyses approaches were used to examine the effectiveness of ST Math for students with ASDs. As a whole, students performed better on post-ST Math assessments, compared to pre-ST Math assessments. Three students completed ST Math consistently and regularly, allowing for the use of Concomitant Time Series Analysis to examine the temporal dynamics between time on task and percentage of items answered correctly. Two of the three students showed significant, positive relationships between time on task and percentage of items answered correctly. Commonalities in the behavioral phenotypes of students who successfully participated in ST Math are compared to the behavioral phenotypes of students who did not. Implications for current practice and future research are discussed.

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Chapter 1: Introduction

Autism, and its associated Pervasive Developmental Disorders (PDDs), have puzzled researchers and clinicians alike over the past 70 years. Now known to be neurodevelopmental disorders with complex genetic and environmental etiologies, Autism Spectrum Disorders (ASDs) affect most, if not all, aspects of development. Kanner (1943) first identified the core symptoms of Autistic disorder in a group of children in the early 1940s. The core symptoms included difficulties in language and communication, inability or unwillingness to engage in social interaction, and odd or repetitive behaviors. Asperger (1944) simultaneously described a set of similar characteristics that would become the foundation for the diagnosis of Asperger syndrome.

Our understanding of ASDs has increased exponentially from these initial descriptions. Much of this knowledge stems from researchers and clinicians working in collaboration to support the translation of knowledge from basic research into clinical practice, as well as the translation of information learned in clinical settings to the application of research in the basic science of ASDs (Rutter, 1999). Such translational research has led to identification of different subtypes of PDDs which has subsequently aided in the development of more specific assessment tools, detailed cognitive and behavioral profiles, and more individualized treatment protocols. However, much remains unknown about the etiology, phenotypic expression, and treatment of these various individual ASDs. In order to continue to expand knowledge about ASDs, cross-

disciplinary collaborative research efforts are needed; ASDs will benefit from continued translational research.

Because there is no medical “cure” for ASDs, treatment includes extensive behavioral and educational interventions (Lord et al., 2005). While comprehensive early intervention packages may alleviate difficulties in social reciprocity, language and communication, and stereotyped and maladaptive behaviors, academic interventions are rarely studied in students with ASDs. Federal law mandates that all students, including those with disabilities, be held to the same high academic standards and that students with disabilities have access to the general education curriculum (Individuals with Disabilities Education Improvement Act [IDEIA], 2004; No Child Left Behind Act [NCLB], 2001). There is a substantial need for research examining the effectiveness of academic interventions, particularly math interventions, for students with ASDs. In the few studies available, reading interventions have been examined but math interventions are routinely neglected (Minshew, Sweeny, Bauman, & Webb, 2005). Implementation of mathematical interventions will help ensure that the achievement of students with ASDs is not ignored.

Statement of Problem

Bridging research and clinical practice across disciplines is a challenge issued by the directors of the National Institutes of Health and National Institute of Mental Health (Zerhouni, 2005; National Institute of Mental Health [NIMH], 2000). Translational research seeks to increase knowledge about human health and behavior by encouraging collaboration between disciplines. Translating basic science knowledge into clinical

practice and back again is essential for broadening our understanding of how disorders can be conceptualized, diagnosed, and treated.

Originally a movement within the biomedical fields, translational research has broadened to include research in behavioral, psychosocial, and educational realms. In particular, translational research has helped expand knowledge of autism and other Pervasive Developmental Disorders in the 70-plus years since the original conceptualization of autism (Rutter, 1999). Basic science researchers have relied on the observations of clinical practitioners to identify increasingly specific delineations of ASDs. Likewise, recognition of the heterogeneity of the biological and genetic mechanisms underlying ASDs has aided in the development of psychosocial diagnostic tools and interventions. Despite widespread advances in the biological and psychological aspects of these disorders, there is still much we do not know about ASDs.

One way in which translational research can continue to increase the ASD knowledge base is through identification of behavioral phenotypes and the subsequent response to intervention of different phenotypes (Riley, 2011). Kazdin (2001) noted that advances in translational research in the medical disciplines arose from identifying specific features of a subgroup of individuals with a given disorder, and examining their response to a treatment. Identification of homogeneous subgroups may stem from identifying common phenotypic expressions, genetic or biological etiologies, or diagnostic categories. Likewise, advances may be made by administering a selected treatment and determining why certain individuals responded by identifying common phenotypes, genetic markers, or diagnostic categories (Guralnick, 2001).

Presently in the field of ASDs, the majority of treatments and interventions are behavioral or educational. Identifying a common cognitive profile has been one method used in clinical and educational settings to aid in diagnosis and to determine outcomes of interventions. While the cognitive abilities of individuals with Autistic disorder have been routinely documented, the cognitive abilities of those with Asperger syndrome and Pervasive Developmental Disorder, Not Otherwise Specified are varied or not well established. Similar attempts at identifying academic achievement profiles have been less prolific and less conclusive across all three ASDs. Rather than rely on one domain such as cognition, comprehensive phenotypes comprised of the behavioral, cognitive, and academic domains should be identified to examine the effectiveness of interventions for students with ASDs.

The study of behavioral phenotypes in individuals with psychiatric and developmental disorders has emerged within the last two decades (Hodapp & DesJardin, 2002). Behavioral phenotypes are sets of characteristics that most individuals with a given disorder display. These characteristics cross all behavioral and developmental domains, such as cognition, language, affect, adaptive functioning, social engagement, etc. Hodapp and Dykens (2007) argue that the identification of behavioral phenotypes for specific disorders will aid in the development of etiologically or phenotypically-specific interventions. Thus, interventions will be more closely matched with the characteristics displayed by an individual with a specific developmental disorder. As noted by Ferrell (2009), this type of study is synonymous with the purpose of translational research: combining basic science knowledge with practical treatment application.

Despite the fact that most students with an ASD receive intervention in educational settings, the education field is routinely neglected in translational research. Federal law mandates that students with disabilities must be provided access to the general education curriculum and appropriate educational services for their disability; educational settings provide a rich field of study for translational research through response to intervention (Individuals with Disabilities Education Improvement Act [IDEIA], 2004). The majority of interventions currently in place target the deficits observed in the ASD symptom triad of communication, social engagement, and repetitive and stereotyped behaviors (Rogers & Vismara, 2008). Despite the legal mandate that students with disabilities be held to the same academic standards as typically developing students, few academic interventions have been studied for students with ASDs. Further, there is a stronger literature base on the effectiveness of reading interventions than on the effectiveness of mathematical interventions. Only five studies have been identified that examined math interventions specifically for students with ASDs (Banda, McAfee, Lee, & Kubina, 2007; Cihak & Foust, 2008; Cihak & Grim, 2008; Levingstone, Neef, & Cihon, 2009; Rockwell, Griffin, & Jones, 2011).

Spatial-Temporal Math (ST Math) is a computerized mathematics instructional program developed by the MIND Research Institute. The program emphasizes learning through visual and spatial methods that are not typical in traditional mathematics curricula. ST Math was selected as an intervention for students with ASDs because it features a number of evidence-based instructional methods that target the strengths and builds on areas of weaknesses of students with ASDs. Strengths-based interventions are

recommended for any psychosocial, behavioral, and academic interventions (Hodapp & DesJardins, 2002). The program primarily uses visual learning techniques, scaffolds learning to meet the level of individual learners, offers consistent and massed practice, and limits social interaction. ST Math has been shown to be effective in increasing mathematical achievement scores on standardized assessments for typically developing students (Rutherford et al., 2010). It has yet to be studied in students with disabilities, including those with ASDs.

Purpose of the Study

The purpose of this study was to explore the relationship between response to a computer-based math supplemental instructional program and phenotypic expression of characteristics of the PDDs of Autistic disorder, Asperger syndrome, and PDD-NOS. More specifically, the relationship between math achievement and attention on the ST Math program was examined. Given the paucity of research on mathematical achievement and mathematical interventions for students with PDDs, it was unknown what individual phenotypic characteristics, if any, relate to mathematical achievement gains in students with ASDs. This study also aided in determining if ST Math warranted larger-scale research study for students with ASDs or children with similar phenotypic expression. A final purpose was to determine if time series analysis, used sparingly as a data analytic technique in educationally-based single case research, is an effective analytic technique for intervention-based single-case research in applied educational settings. As a whole, this study examined individual response to a mathematical academic

intervention using a framework that will aid in bridging research in the identification of ASD phenotypes, and ultimately, etiology.

Research Questions

1. Given the potentially strong match between the learner characteristics of individuals with ASDs and the features of ST Math, does the ST Math program affect mathematical achievement in students with ASDs?
2. Given the potentially strong match between the learner characteristics of individuals with ASDs and the features of ST Math, does the ST Math program affect on-task attention time in students with ASDs?
3. Is there a relationship between ST Math-related attention and achievement?
4. Does individual response to the ST Math program differ based on behavioral phenotypic expression?
5. What are the strengths and weaknesses of time series analysis as an analytic technique for intervention-based single-case research in applied educational settings?

Study Significance

Substantive significance. This study targeted a minimally researched area in ASDs (math intervention) using a translational research framework. As per Hodapp and Dykens' (2007) call for behaviorally-specific interventions, the relationship between individual phenotypic profiles and intervention effectiveness was examined. This, in turn, may be useful in future identification of more specific phenotypically-defined subgroups

of ASDs. The study provides initial information regarding a strengths-based phenotypic-specific intervention.

Research on mathematical achievement and mathematical interventions for students with ASDs is minimal, at best. The application of math achievement standards to students with ASDs is nonexistent. There exists a major gap in the ASD literature on both math achievement and math interventions. At a minimum, this study contributed to the knowledge base of a potential mathematical achievement intervention for students with ASDs.

Methodological significance. The study used a combination of single-case design and comparative methods. Single-case design is a necessary research methodology to examine intra-individual differences and variability in intervention research, particularly when there is minimal or no information regarding the intervention outcomes. Further, academic achievement progress is often not adequately measured by traditional standardized assessments or curriculum based measures. This study allowed for the examination of an alternative method of academic achievement data collection for students with ASDs. This then provided information regarding the need for further examination of ST Math in a traditional between-groups research design.

Analytic significance. Concomitant time series analysis (CTSA), although recognized as an alternative to traditional visual analysis in single subject research, has rarely been used in educational research. Yet learning is a dynamic process that is not well measured by traditional pre-post or cross-sectional studies. CTSA provides an alternative analytic technique that specifically examines the temporal relations of

dynamic processes (West & Hepworth, 1991). Further, because intervention research for low incidence disabilities such as autism often must rely on single case design in early stages, an analytic technique that accounts for multiple observations of a single subject over time is needed.

Definition of Key Terms

Autism Spectrum Disorders (ASD): a collection of developmental disorders identified by a similar set of characteristics, including repetitive behaviors, impaired language and communication, and impaired social skills.

Autocorrelation: a relation between an observation and leading and/or lagging observations in a data series.

Autoregressive Integrated Moving Average model (ARIMA): a time series analytic technique that co-examines autoregressive and moving average components in a time series.

Behavioral phenotype: the likelihood that those with a particular disorder or syndrome will display specific behavioral or developmental sequelae in relation to those without the disorder.

Computer-assisted instruction (CAI): use of technology, primarily through a personal computer, to provide educationally-based instruction.

Concomitant Time Series Analysis (CTSA): an analytic technique that accounts for the non-independent relationship between data observations over repeated measures in systems or processes expected to change over time.

Individuals with Disabilities Education Improvement Act (IDEIA): Public law renewed in 2004 to provide students with disabilities a fair and appropriate public education.

No Child Left Behind: Public law enacted in 2001 and renewed in 2010 that describes the achievement requirements for students in public education settings.

ST Math: a picture-based computer assisted mathematical intervention program.

Translational research: how basic processes inform the diagnosis, treatment, and delivery of services for health problems and how knowledge of health treatments increases our understanding of basic biological processes.

Chapter 2: Review of the Literature

Within the last two decades, there has been a widespread call for implementation of translational research in the health sciences (Zerhouni, 2005). Translational research originated in the biomedical field as scientists, clinicians, and funding agencies recognized the disconnect between basic scientific research and application of such research to practical settings. Only a small percentage of original basic research actually transfers to clinically relevant information, and this transfer may take up to 20 years (Palinkas & Soydan, 2012). In 1998, the National Institutes of Health (NIH) called for a bridging of the gap between basic research and community-based treatment by translating advances “from the bench or animal laboratory” to clinical application, specifically for substance abuse disorders. Thus, the translational research descriptor of “from bench to bedside” was born (Nunes, Carroll, & Bickel, 2002, p. 155). As the value of translational research was increasingly identified, the NIH instituted a substantial policy shift. In 2005, the NIH developed the Roadmap for Medical Research to encourage translational and cross-disciplinary research (Zerhouni, 2005). Numerous funding sources were made available for laboratory scientists and community practitioners willing to engage in such collaboration, the Journal of Translational Medicine was developed, and academic institutes were encouraged to determine if their professional growth criteria hampered translational research efforts (i.e., tenure, number of first author publications, number of NIH RO1 grants) (Morgan et al., 2011).

Despite the significant interest in translational research, the movement is truly nascent, as evidenced by a lack of consistent definition. Numerous definitions have been suggested by different scientists and agencies. Mace and Critchfield (2010) provided a quite general definition of translational research as “inquiry that breaks new ground by uniting a concern for fundamental principles with a concern for everyday problems and outcomes” (p. 296). The definition from the National Institute of Neurological Disorders and Stroke is “the process of applying ideas, insights, and discoveries generated through basic scientific inquiry to the treatment or prevention of human disease” (as cited in Cicchetti & Toth, 2006, p. 619). The National Academy of Sciences, as cited in Cicchetti & Toth, 2006, p. 620, describes translational research in terms of interdisciplinary collaboration:

A cooperative effort by a team of investigators, each of whom is an expert in the utilization of different methods and concepts and who have united in an organized manner to address a challenging problem.

Based on a collection of definitions from various agencies and translational scientists, Cuthbert (2007) suggested that the term “translational research” has been used to define three different activities. First, he noted that some identify translational research as basic research that informs the study of abnormality (physical, behavioral, etc.), without the application of the information to treatment. However, others use the term to describe how basic research informs treatment and prevention of diseases through increased understanding of basic mechanisms of pathology. Finally, translational research has also been used to describe the dissemination of new treatments to public health sectors, also known as dissemination research. The term “translational research” is used

differently dependent on the purpose of the source. However, Ferrell (2009) stated that the overarching goal of all translational research, regardless of the definition, “is to improve human health and significantly decrease the burden of disease” (p. 10).

While there is a lack of a consistent definition, the definitions tend to suggest a one-way direction between basic and applied science, in that basic research informs application. However, it is generally agreed that there is a reciprocal relationship between scientific research and clinical application. That is, translational research not only describes research that translates advances from laboratories to clinical settings, but it also describes research that informs basic science through clinical observation. Advances in each setting inform advances in the other, with the goal of overall improved health (Cicchetti & Toth, 2006).

The behavioral and social sciences have similar interest in increasing translational research, but it has been much slower to emerge in these fields (Cicchetti & Toth, 2006). In 2000, the National Institute of Mental Health’s National Advisory Mental Health Council formed the Behavioral Science Workgroup to identify and recommend ways to foster translational research in the behavioral sciences. NIMH leaders recognized that although the agency supported a substantial amount of basic research and clinical research separately, they were not effectively supporting research that connected the two forms. The Workgroup first developed a definition of behavioral translational research: “how basic behavioral processes inform the diagnosis, treatment, and delivery of services for mental illness and conversely, how knowledge of mental illness increases our

understanding of basic behavioral processes” (p. 2). This definition is reflective of the bidirectional nature of translational research.

The Behavioral Science Workgroup then identified three areas of priority research that would aid in establishing a strong translational behavioral science research program at NIMH. The first priority research area identified was increased understanding of basic behavioral processes in mental illness. Within this broad domain, the Workgroup identified a need for research that examines not only how basic behavioral processes are altered in mental illness and behavioral disorders, but also research that increases understanding of how these basic behavioral processes inform etiology, assessment, prevention, and intervention of a given disorder. Further, the Workgroup recommended fostering collaboration between neuroscience, pharmacology, and genetics to lead to an integrated approach to understanding emotional and behavioral disorders.

The second priority research domain is that of functional abilities in mental illness. Research should examine how the presence of mental illness, combined with the reception of some sort of treatment, affects the ability to function in a diverse group of community settings (ranging from residential treatment to the workforce). Finally, the Workgroup suggested that priority research also focus on how various contexts influence mental illness and treatment. The Workgroup recognized that ecology affects mental illness etiology and outcome. Thus, they placed an emphasis on better understanding how familial, cultural, environmental, and organizational factors affect individuals. Together, research in the three identified priority areas will contribute to a stronger translational research framework in the nation’s leading behavioral science funding agency.

Research in the behavioral and psychological sciences is often pertinent to the field of education. Yet, translating basic psychological and behavioral research into education practice is even less developed than translational research within the psychological sciences. White, Frishkoff, and Bullock (2008) reviewed a set of studies, showing that bridging research and educational practice may improve student achievement. In the educational domain, they define translational research as:

Extending knowledge about human learning, memory, and cognition while addressing practical questions about optimal learning in particular domains and about optimal methods of instruction in real-world contexts (p. 220).

Laboratory-based research in cognition has advanced understanding of student learning in schools, which has led to the development of instructional techniques. The authors suggested that subsequent research on these instructional techniques has shown that they lead to increased student achievement. Increased achievement is the goal of translational research in education as it is synonymous with the goal of improving human health in the biomedical fields. According to Riley (2011), the next step in translational research is to bridge the gap between the fields of medicine, psychology, and education to ensure the academic and social success of children.

DeVries and Oliver (2009) opined that intellectual disabilities and genetic disorders should be pioneering translational research medically, behaviorally, and educationally. The authors recognized that there is a commonly held belief that once these disorders have been diagnosed, special education and environmental supports are the only interventions available. However, they argue that such disorders, especially those with a known genetic etiology, can serve as templates for the development of

behavioral and psychopharmacological treatments. More specifically, Rutter (1999) stated that autism is an example of a disorder that has benefited from translational research. He noted that clinical practice for people with autism “has changed out of all recognition in the last half of the century” (p. 182) because of advances made through researchers and clinicians working collaboratively. Rutter elucidated this claim by delineating the history of autism from the original concept of autism as a form of childhood schizophrenia to the present principle of a spectrum of disorders. However, given the controversy that surrounds differentiating ASD diagnoses, translational research must be applied to this collection of developmental disorders more routinely and methodically.

Translational research is a relatively new movement designed to encourage reciprocal relationships between basic science and clinical practice. While it is more heavily applied in biomedical research, translational research is gaining ground in the behavioral, psychological, and educational sciences. Translational research has been particularly useful in developing our knowledge of ASDs; there are now calls for increasingly applying such knowledge to treatment. Because much is still not known about the causes, processes, and treatments of ASDs, there is further need for collaboration between researchers and clinicians across disciplines.

Intervention Specificity and Differential Diagnosis

In their report regarding the state of behavioral science research at the NIMH, the National Advisory Mental Health Council’s Behavioral Science Workgroup identified a basic question that translational research should seek to answer: “What works for whom

and under what circumstances?” (2000, p. 21). The Workgroup stated that researchers should seek to determine more than whether or not a treatment or intervention works. Instead, specifics of the intervention should be evaluated concurrently with characteristics of the individual(s) receiving the intervention and the contextual factors to determine effectiveness. The Workgroup noted that group-differences research, so common in psychological research, is no longer sufficient to answer this question. Rather, exploratory analyses capitalizing on the knowledge gained from basic science should be used to identify individual differences in intervention progress and outcomes.

This sentiment was echoed by Kazdin (2001), although he was commenting in relation to therapy specifically. He noted that although there are hundreds of documented psychological and behavioral interventions for children and adolescents, there is a small research base documenting the mechanisms and processes of intervention efficacy. In order to better understand what treatments work, with whom, and under what conditions, Kazdin advocated for subgrouping or subtyping groups of individuals with a given disorder. He noted that significant medical advances have developed from delineating similar characteristics in a subgroup of people with a condition, applying treatment to the subgroup, and expanding or retracting treatment to others based on small group response to treatment.

Similarly, the NIMH (2000) stated that identifying very specific phenotypes of behavioral and emotional disorders is important for success in translational research. A phenotype is the observable aspects of a given genetic make-up. Phenotypes are usually associated with the physical characteristics of a biological organism. The identification of

well-defined behavioral or psychological phenotypes allows basic scientists to better examine etiologies of behavioral, emotional, or developmental disorders, and allows practitioners to better understand response to interventions. Combining disorders with only mildly similar phenotypic expressions in research can complicate the identification of genetic and neurological causes, as different phenotypes may have different etiologies. Likewise, in order to determine “what works for whom, and under what circumstances,” applied science must be able to rely on increasingly differentiated subgroups with a disorder as a way to meet the call for increasingly differentiated treatment.

The field of early intervention has readily adopted a translational framework based on the identification of homogenous subgroups of children with a given disorder (Guralnick, 1997/2005). The success in applying basic science knowledge to early intervention has been credited in the search to identify core processes that contribute to developmental problems, specific to subgroups of children with a disorder. Identifying these core processes allows researchers and clinicians to specify developmental profiles that can distinguish between children with different disabilities. Further, the field has been able to translate knowledge of these core processes (basic science) into interventions that either strengthen or compensate for the deficits. As a result, interventions are more specific and individualized for a disorder and for individuals.

Guralnick (2005) suggested that subgrouping of children with a given disorder can occur through a variety of mechanisms. First, differentiation can occur based on the etiology of a disorder. For example, children with Down syndrome and children with fragile X syndrome are differentiated etiologically because each disorder has a different

genetic cause. Subgroups can also be identified based on a categorical diagnostic system, such as Autistic disorder versus Pervasive Developmental Disorder, Not Otherwise Specified. Finally, phenotypic subgroups can be identified in which the developmental characteristics of individuals are differentiated. Guralnick also noted that one method of subgrouping can inform research of another method of subgrouping. For example, differentiating children with autism based on phenotypic expression may ultimately assist in the identification of etiologically different groups. Subsequently, intervention and treatment can be more precisely tailored based on a more specific definition or profile of a disorder.

Behavioral Phenotypes

Guralnick (1997/2005) has suggested that identification of individuals based on phenotypic presentation is one way to identify subtypes of disorders and subsequently, to individualize treatment. Dykens and Hodapp (1997/2007) argue that the identification of etiologically specific behavioral phenotypes is essential to both basic science and treatment research. Dykens (1995) defined a behavioral phenotype as “the heightened probability or likelihood that people with a given syndrome will exhibit certain behavioral or developmental sequelae relative to those without the syndrome” (p. 326). Thus, individuals with a given disorder of a known etiology (such as Down syndrome) will typically display a distinct behavioral pattern that is different than what an individual with a different disorder will show. There are several corollaries to this definition, as identified by Hodapp and Dykens (2004). First, not every individual will demonstrate the profile or behavior problem of the syndrome, thus phenotypes are probabilistic. Second,

some etiology-specific behaviors will be unique to a single syndrome, while others are common to two or more syndromes. This is known as partial specificity. Third, phenotypic behaviors change with age; a developmental framework is necessary when considering the behavioral phenotype. Finally, etiology-related behaviors occur across many behavioral domains. Thus, identification of phenotypes can be based on cognitive, linguistic, maladaptive behaviors, psychiatric behaviors, or other domains, as well as combinations of these domains.

These authors have studied behavioral phenotypes in relation to intellectual disability in genetic disorders with identifiable causes such as Williams syndrome and fragile X syndrome. However, the notion of etiologically-specific behavioral phenotypes can be useful in the identification of behavioral profiles in individuals with ASDs (Dykens, Sutcliffe, & Levitt, 2004). It is accepted that ASDs have heterogeneous etiologies, but that these etiologies remain unknown. However, identification of specific behavioral phenotypes can aid research in locating genetic or genetic-environmental causes of different subtypes of ASDs. Further, as Hodapp and Dykens have stated, “etiology based research is important for more specific, targeted interventions” (2007, p. 216). They note that very few studies have examined the efficacy or effectiveness of etiologically-specific interventions. However, if a behavioral phenotype that is characterized by strengths and weaknesses is known, then intervention can be targeted to either build on strengths or ameliorate weaknesses. Often interventions are designed to alleviate or compensate for weaknesses. Hodapp and DesJardin (2002) advocated for a strengths-based approach to intervention. This is based on the notion that basic science in

etiologically-specific syndromes contributes to the treatment of an individual. If interventions are designed based on the phenotypic profile of the individual, they become much more individualized. Here again is a reflection of the importance of translational research in the treatment of disorders.

Autism Spectrum Disorders

Pervasive Developmental Disorders (PDDs) and Autism Spectrum Disorders (ASDs) are two terms used to describe a collection of developmental disorders identified by a similar set of characteristics. The characteristics generally associated with these developmental disorders are pervasive impairments in communication or language, pervasive impairments in social interaction, and repetitive, stereotyped behaviors. PDD is an umbrella diagnostic category in the *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition Revised* (American Psychiatric Association [DSM-IV-TR], 2000). Currently, five disorders fall under this umbrella term: Autistic disorder, Asperger syndrome, Rett's disorder, Childhood Disintegrative disorder, and Pervasive Developmental Disorder, Not Otherwise Specified. ASD is a term used more informally in research and clinical settings to describe a continuum of impairments that are synonymous with the major characteristics. It is typically used to describe the three major PDDs of Autistic disorder, Asperger syndrome, and PDD-NOS. An official clinical diagnosis of ASD cannot currently be made (Volkmar, 2005). The two primary psychological disorder classification systems, the *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition Revised* (American Psychiatric Association [DSM-IV-TR], 2000), and the *International Classification of Diseases, 10th Edition* (World Health

Organization [*ICD-10*], 1992), converge on all major characteristics or symptoms of ASD, namely the triad of symptoms that categorize ASDs. Individuals with an ASD may exhibit difficulties in one or all of the triadic categories of socialization, communication, and repetitive and non-functional behavior. The term ASD will be used throughout this manuscript when general descriptions are necessary. When considering a specific diagnostic category, the appropriate term (Autistic disorder, Asperger syndrome, PDD-NOS) will be used.

Diagnosis in Autism Spectrum Disorders. There is currently much debate about whether the PDDs identified in the *DSM-IV-TR* (2000) represent distinct diagnostic categories or if they are manifestations of differing severity of one single disorder. It had been widely accepted that ASDs are heterogeneous, and that more specific diagnostic categories such as Asperger syndrome or PDD-NOS also describe heterogeneous groups of individuals. The history of the autism diagnosis has changed over the past 60 years. Originally thought to be a manifestation of schizophrenia, the most commonly accepted belief now is that autism is represented on a spectrum, and people differ in regards to the quantity and severity of autism they have (Rutter, 1999; Dixon, Garcia, Granpeesheh, & Tarbox, 2009). This notion of a spectrum of symptoms is likely to dictate how the next edition of the *Diagnostic and Statistical Manual of Mental Disorders (DSM-V)* conceptualizes and recommends diagnosis for autism. As the *DSM-V* editors continue to revise standards, researchers and clinicians continue to debate whether such a diagnostic system will affect diagnosis and treatment of those with ASDS (Wing, Gould, & Gillberg, 2011). However, researchers on both sides of the debate have conceded that

there is not enough evidence for or against the conceptualization of PDDs as a spectrum of continuous disorders. Thus, until studies can quantitatively and qualitatively identify autism-like phenotypic characteristics without relying on predetermined *DSM-IV* diagnosis, one diagnostic conceptualization cannot be deemed more accurate than another (Frith, 2004).

Current diagnostic conceptualizations. After Kanner's (1943) original clinical description of autism, scientists and clinicians attributed the disorder to a childhood form of schizophrenia. Indeed, in the 1940s and 1950s autism was referred to as schizophrenic syndrome of childhood or infantile psychosis. However, in the 1960s, researchers initiated systematic evaluations of the characteristics of autism. In the first efforts of a syndrome definition, Lockyear and Rutter (1969) used comparison groups and direct observation to determine characteristics that manifested only in autism. Through this early form of replicated research, the triad of symptoms was accepted as a model definition for autism, and the diagnosis of childhood schizophrenia was abandoned (Rutter, 1999). As research shifted towards identifying the etiology of autism in the late 1970s and early 1980s, differential diagnosis again came into play. Variations in the presentation of amount and intensity of the triad of symptoms were consistently noted. Clinicians and scientists alike recognized the heterogeneity of the "autism" diagnosis and moved towards a differential classification system. This laid the foundation for the classification of PDDs with four separate diagnoses in the *DSM-III* (1980), and later, five in the *DSM-IV* (1994). From early in the history of autism, diagnostic categories have

been developed and refined to reflect gains in knowledge from both basic and applied research.

Despite increased recognition of the symptoms of autism, diagnostic heterogeneity remains a much debated issue. Among the three main diagnostic categories of Autistic disorder, Asperger syndrome, and PDD-NOS, there is substantial variation in symptom amounts and intensities, and abilities. Thus, clear cut PDD diagnoses are often difficult to make. Much of the confusion of diagnosis has been attributed to reported problems with the *DSM-IV*. Several concerns regarding diagnosis of PDDs using the *DSM-IV-TR* have been identified (Witwer & Lecavalier, 2008). First, High Functioning Autism (HFA) is a term clinicians use to describe people with Autistic disorder with an IQ above 70. However, it is not included in the *DSM-IV-TR* as an official diagnosis. Given that typical cognitive ability is a component of Asperger's syndrome, many clinicians struggle with differentiating HFA from Asperger's syndrome. It is unclear if HFA and Asperger's syndrome are two distinct disorders or if they are variations of the same disorder (Dixon et al., 2009). Thus, numerous studies have been undertaken to determine if these disorders are in fact separate, with mixed results (Macintosh & Dissanyake, 2004). Some studies have reported no differences in cognitive, behavioral, or other phenotypic expressions, while others have been able to differentiate between the disorders based on some underlying characteristic.

A second common concern with the *DSM-IV* is the fact that diagnoses of all PDDs is based on the number of symptoms an individual displays. For example, to be diagnosed with Autistic disorder, two or three symptoms in each of three areas must be

observed. If an individual does not meet the cut-off number, then according to the *DSM-IV-TR*, they do not have the specific disorder. Similarly, diagnoses of Asperger syndrome and PDD-NOS are only made after a diagnosis of Autistic disorder is ruled out. These disorders are then, by definition, default diagnoses (Walker et al., 2004). If an individual exhibits fewer Autistic disorder symptoms than the *DSM* guidelines, a PDD-NOS or Asperger syndrome diagnosis is made (Towbin, 2005). The category of PDD-NOS is considered by most clinicians to be a “catch-all” diagnostic category that actually represents a very heterogeneous group of people. This diagnosis tends to be given when there are apparent differences in individuals, but they do not meet clear diagnostic criteria for Autistic disorder or Asperger syndrome. Yet, there has been limited research of the qualitative differences in symptom expression between PDD-NOS and Autistic disorder (Walker et al.). Finally, because all PDDs are commonly comorbid with other psychological and medical disorders, the boundaries between diagnostic entities are further blurred. These issues have led to increasing frustration with the current diagnostic system for ASDs, and a call for an approach that may better reflect an underlying spectrum of disorders.

In calls for improving the next version of the *DSM*, some researchers believe that behavioral and emotional disorder diagnoses, including autism, should be based on a dimensional framework, as opposed to the categorical framework currently used in the *DSM-IV-TR*. While the *DSM-IV-TR* does not assume that each diagnostic category is a separate and distinct disorder with no overlap between disorders, the manual does state that it is a classification system “based on defining disorder features” (2000, p. xxxi). In a

dimensional model of diagnosis, diagnoses are made on the basis of significant difference from the general population based on the normal curve. Thus, differences among people represent differences in the severity of a homogenous concept (Widiger & Samuel, 2005).

Numerous factor analyses of potential spectrum symptoms have been undertaken since the inclusion of Asperger syndrome in the *DSM-IV*. The purposes of these factor analyses have been to empirically derive accurate characterizations of autism-like disorders and to show support for the conceptualization of PDDs as a spectrum of disorders. However, many of these studies use children with *DSM* predefined diagnosis, or they use symptom exhibition based on the Autism Diagnostic Interview-Revised ([ADI-R], Le Couteur, Lord, & Rutter, 2003) or the Autism Diagnostic Observation Schedule ([ADOS], Lord, Rutter, DiLavori, & Risi, 1999), both assessments derived from the *DSM-IV* categorical diagnoses. There has been general agreement of three clusters of diagnoses among the studies. However, the three clusters are not always similar between research studies and do not always match the *DSM-IV-TR* diagnostic categories of Autistic Disorder, PDD-NOS, and Asperger syndrome (Dixon et al., 2009).

Rather than use symptoms as defined by ASD assessment scales such as the ADI-R or the ADOS, Bitsika, Sharpley and Orapelend (2008) used cognitive, adaptive, and behavioral measures to identify the presence of ASD subgroups in a sample of 53 children. Recognizing the usefulness of subgroups or separate profiles of ASD, the authors proposed that identification of profiles beyond those identified by common autism assessments may advance individualized intervention. Based on results from the Wechsler Intelligence Scale for Children, 4th Edition, the Vineland Adaptive Behavior

Scales, 2nd Edition, the Childhood Autism Rating Scale, and a newly developed behavioral scale, cluster analyses revealed three clusters of diagnoses. The authors labeled these groups as Low Functioning (consisting primarily of individuals diagnosed with Autistic disorder), Moderate Functioning (consisting mostly of children diagnosed with Asperger's syndrome), and High Functioning (consisting entirely of children with Asperger's). Despite the labels given to the groups, the clusters were differentiated more on number of symptoms than on level of functioning. This is the first study that is known to have used indices other than the ADI-R or ADOS to determine a cluster-analysis profile for subgroups of children with autism. Yet, the results do not provide any new evidence regarding the effectiveness of one diagnostic conceptualization over another.

Despite ongoing advances in diagnosis, there is speculation that even more subgroups of PDDs exist (Volkmar, State, & Klin, 2009). Reflective of a translational research model, Volkmar et al. expressed hope that these hypothetical subgroups can be identified through discovery of specific etiologies or physiological mechanisms. The authors go on to state that defining phenotypically similar subgroups based on clinical observation will also be important in the search for genetic and biological factors in autism. This bi-directionality is the core of translational research. Identification of more specific subgroups of PDDs will increase specificity and individualization of interventions, thereby promoting well-being for people with various types or degrees of ASDs.

It is generally recognized by most, including those who support a spectrum or dimensional diagnostic system, that specificity in diagnosis for research purposes allows

for identification of more homogenous groups and subsequently aids in treatment development (Kampe-Becker, Smidt, Ghahreman, Heinzl-Gutenbrunner, Becker, & Remschmidt, 2010). Further, proponents of both arguments agree that the current systems and conceptualizations of diagnosis do not adequately address individual characteristics and how these characteristics aid in intervention development (Dixon et al., 2009). Accordingly, more research on ASD genotypes and phenotypes needs to be conducted in order to further identify more detailed characteristics of ASD subtypes. These distinctions will ultimately assist in the specialization of treatment and intervention for individuals with autism, which is the goal of translational research.

Accordingly, it is not the intent of this project to show support for one diagnostic system or another. Further, it is beyond the scope of this project to determine how the current diagnostic system should be modified to account for new findings in ASD research. The purpose is to support the identification of behavioral phenotypes in individuals with ASDs based on an etiologically-specific translational research framework and examine the relationship between such phenotypes and individual response to an academic intervention.

Current *DSM-IV-TR* categories. As previously noted, the *DSM-IV-TR* (2000) classifies the five PDDs as Autistic disorder, Asperger syndrome, PDD-NOS, Rett's disorder, and Childhood Disintegrative disorder (CDD). Rett's and CDD are usually differentiated from the other three PDDs; Autistic disorder, Asperger syndrome and PDD-NOS are typically referred to as ASDs. The *DSM-IV-TR* is the primary mechanism through which ASD diagnoses are currently made. The following section describes the

history and diagnostic information for the three most common PDDs: Autistic disorder, Asperger syndrome and PDD-NOS.

Autistic Disorder. Kanner (1943) was the first to describe a set of core features that later became the diagnostic basis for Autistic disorder. Kanner identified a set of characteristics that were common to eleven children he observed and evaluated. He found that these children were uninterested in their social milieu, were mute or engaged in echolalia, and were overly sensitive to certain aspects of the environment or changes in the environment. Kanner applied the term *autism* to these children, taken from Bleuler (1911/1951) who used the term to describe egocentric or self-centered thinking. This led to an early assumption that autism was a developmentally early form of schizophrenia (Bender, 1946). Moreover, the first (1952) and second (1968) editions of the *DSM* used the term “childhood schizophrenia” to describe children with what is now known as Autistic disorder. Only through studies of the life course and family history of those with autism and those with schizophrenia did a clear distinction emerge by the late 1970s (Kolvin, 1971).

Although Kanner was the first to posit that these characteristics were due to an inborn error in metabolism, he also noted that the children with autism and their parents had significant relational problems. From this observation stemmed a decades-long debate about the cause of Autistic disorder. Through the 1960s, Autistic disorder was considered to be a result of poor or “frigid” parenting (Volkmar & Klin, 2005). However, causal theory shifted to an internal psychological disturbance model when it was suggested that problems in relational interactions stem from the child’s difficulty, rather

than the parents' parenting ability (Mundy, Sigman, Ungerer, & Sherman, 1986). More recently, neuroscience research has pointed to brain-based differences in people with ASDs (Minshew, Sweeny, Bauman, & Webb, 2005). Further, genetic studies have identified chromosomes and genes of interest that may contribute to the development of Autistic disorder (Shao et al., 2003). Today, it is generally accepted among the science and medical communities that autism develops from a complex interaction of biological (genetic) and environmental factors (Volkmar & Klin). The cause of autism remains unknown.

The diagnosis of an ASD is a complex process that currently relies, in part, on some set of diagnostic criteria. Numerous sets of criteria have been developed. The most commonly used diagnostic criteria in the United States is from the American Psychiatric Association's *DSM-IV-TR* (2000). According to the current *DSM-IV-TR* classification system, for a diagnosis of Autistic disorder to be made, an individual must exhibit six criteria among all three symptom domains. Two criteria must be evident in the first domain, impairment in social interaction. The possible criteria are: impairment in the use of nonverbal behaviors and gestures in social interaction, inappropriate or nonexistent peer relationships, or lack of spontaneous shared enjoyment. One criterion must be specific to communication impairment: delay or lack of spoken language, impairment in initiating or sustaining a conversation, stereotyped and repetitive language, or lack of imitative social play. An individual must exhibit at least one of the following criterion related to stereotyped patterns of behavior, interest, or activities: restricted or stereotyped interest abnormal in either intensity or focus, engagement in nonfunctional routines,

stereotyped and repetitive motor movements, or preoccupation with parts of objects. Finally, onset must have occurred in at least one domain prior to age three (*DSM-IV-TR*). The *International Classification of Diseases, 10th edition (ICD-10, 1992)*, used in international settings, essentially has the same diagnostic criteria for Autistic disorder as the *DSM-IV-TR*.

Asperger Syndrome. As Kanner (1943) evaluated and described a group of children he would later identify as autistic, Hans Asperger (1944) concurrently identified a group of children who displayed typical cognitive abilities combined with adequate or even superior verbal language skills. However, these children exhibited poor socialization skills and had narrow, focused interests—two features common in the ASD symptom triad. Asperger’s delineation of the characteristics he observed as “autistic personality disorders in childhood” or “autistic psychopathy” became the basis for what is now known as Asperger syndrome (*ICD-10*) or Asperger’s disorder (*DSM-IV-TR*).

Asperger’s work was not translated into English until the 1970s. Thus, Kanner and Asperger were seemingly unaware of each other’s work and did not appear to engage in categorical differentiation of the two diagnoses. However, Wing (1981) published a review of 34 case reports which differentiated 19 cases that were synonymous with Asperger’s original clinical conceptualization and 15 cases that did not display early history of symptoms. Wing’s review first identified the triad of symptoms that exist in the Autism Spectrum of disorders.

Given that there exist at least five different diagnostic systems of Asperger syndrome, clinicians and scientists continue to struggle with differentiating Asperger

syndrome from Autistic disorder and High Functioning Autism (Klin, McPartland, & Volkmar, 2005). The most commonly agreed upon characteristics of Asperger syndrome are social impairment, restricted and stereotyped interests, and motor difficulties or clumsiness. According to the *DSM-IV-TR* classification, Asperger disorder is met when one exhibits two or more characteristics of social impairment and two or more characteristics of restricted patterns of behavior. The characteristics of social impairment are: impairment in multiple nonverbal social regulation behaviors such as eye-to-eye gaze, facial expression, body posture, and gestures; failure to develop appropriate peer relationships; lack of spontaneous shared-enjoyment or interest seeking; lack of social or emotional reciprocity. The characteristics of stereotyped behavior are: preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus; inflexible adherence to specific, nonfunctional routines; stereotyped and repetitive motor mannerisms; persistent preoccupation with parts of objects. Finally, the *DSM-IV-TR* also states that, unlike children with Autistic disorder, children with Asperger disorder have no early language or cognitive delays.

The *ICD-10* diagnostic guidelines for Asperger syndrome are synonymous with the *DSM-IV-TR*. Thus, according to the two major diagnostic systems, the primary differences between Autistic disorder and Asperger syndrome are age of onset of concerns, evidence of cognitive and language delay, and number of social impairment and stereotyped behavior symptoms.

Pervasive Developmental Disorder, Not Otherwise Specified (PDD-NOS).

PDD-NOS is considered by many to be a “catch-all” or “fall-back” diagnostic category in

the *DSM-IV-TR* (Towbin, 2005). The *DSM-IV-TR* identifies PDD-NOS as a developmental disorder comprised of fewer symptoms than is typical of Autistic disorder or with a later onset of symptoms than age three (2000). Typically, those diagnosed with PDD-NOS exhibit qualitatively similar symptoms in the triad of social reciprocity, communication difficulties, and stereotypic behavior. However, these individuals tend to display fewer symptoms or have more mild symptoms, and thus a better prognosis.

PDD-NOS first emerged as a separate diagnostic category in the *DSM-III* (1980) to account for individuals who displayed social reciprocity difficulties but did not meet criteria for Autistic disorder. In its current *DSM-IV-TR* conceptualization, PDD-NOS is primarily a disorder of impairments in social interaction that may also be combined with language impairments *or* stereotypic behavior, as opposed to both (2000). Rather than meet criteria for a set number of symptoms in all three symptom domains (as per Autistic disorder), PDD-NOS is a subthreshold category. Thus, individuals who do not meet full criteria for Autistic disorder or Asperger syndrome may meet the PDD-NOS criteria. The *IDC-10* subthreshold category is called PDD-unspecified and is not as broad as the *DSM-IV* classification (1992). The PDD-NOS diagnostic concept has been criticized for its lack of clarity and specificity. Further, it is presumed that the biological and genetic underpinnings of those diagnosed with PDD-NOS varies significantly, more so than those with Autistic disorder and Asperger syndrome, offering suppositions of further PDD subgroups (Towbin, 2005).

Prevalence and incidence. In 2009, 1 in 150 children received an Autism Spectrum Disorder diagnosis. By 2010, it was believed nearly 1 in 110 were diagnosed

with an ASD. Recently, the Center for Disease Control reported that 1 in 88 children now have an Autism Spectrum diagnosis (Center for Disease Control, 2012). The diagnosis is more common in males than females; 1 in 58 males have an Autism Spectrum diagnosis (CDC, 2012). These diagnoses cross all socio-economic levels and racial groups (Mayes & Calhoun, 2011).

In an attempt to determine the best estimates of the prevalence of the PDDs, Fombonne (2006) reviewed and synthesized the results of population studies. Based on estimates from a multitude of population studies, the most recent prevalence estimate for all PDDs is at least 36.4 per 10,000, but could be as high as 40 to 45 per 10,000. PDD-NOS is the most common PDD, with estimates of 20.8 per every 10,000. The prevalence of Autistic disorder is between 10 per 10,000 and 16 per 10,000. Thus, Fombonne suggested a midpoint of 13 per 10,000 as the best prevalence estimate of Autistic disorder. The prevalence of Asperger syndrome has ranged from estimates of 2 per 10,000 to 14 per 10,000. However, Fombonne noted that the lack of a specific, well-defined diagnostic classification system for both Asperger syndrome and PDD-NOS makes precise estimates extremely difficult (2005). Thus, until these two diagnostic categories are better defined, prevalence studies should be interpreted with caution.

ASD Phenotypic Profiles

Cognitive profiles. Originally it was thought that as many as 75% of people with Autistic disorder had an intelligence quotient (IQ) below 70. However, it is now estimated that this number is closer to 50% (Lord & Spence, 2006). An IQ of 70 or below signifies substantial intellectual deficits, and when combined with significant adaptive

functioning deficits, represents Intellectual Disability (ID). Thus, a substantial number of children with Autistic disorder have a comorbid diagnosis of ID (Lord & Spence). High-Functioning Autism (HFA) had until recently been used synonymously with Asperger syndrome. However, there is tentative acceptance of the term High-Functioning Autism to describe individuals with minimal or no cognitive delay but impaired language and social interactions. The HFA term has been applied to people with a diagnosis of Autistic disorder but with an IQ in the average or above average range (Noterdaeme, Wriedt, & Hohne, 2010).

Despite the large percentage of children and adolescents with IQs in the Intellectually Disabled range, a full range of IQ scores is evident in the Autistic disorder population. Scores ranging from a low of 35 to a high of 170 have been identified in individuals with Autistic disorder (Mayes & Calhoun, 2003). In research spanning four decades, attempts to identify a cognitive profile representative of Autistic disorder, particularly in children and adolescents, have repeatedly been made. The primary aims in doing so are to aid in diagnosis, treatment, and intervention development.

Replication after replication has shown that individuals with Autistic disorder present with an uneven cognitive profile (Happe, 1994; Charman et al., 2011). Generally, individuals with Autistic disorder perform better on cognitive tasks that require the use of visual and perceptual processing, and perform worse on language-based and verbal comprehension tasks. The lack of language or significant language impairments common in Autistic disorder negatively affects the ability to learn and subsequently synthesize and convey verbally-based information. Thus, tasks such as defining words and describing

abstract relationships are challenging to individuals with Autistic disorder. Similarly, deficits in social interactions and social awareness affect performance on practical problem solving tasks common to the assessment of verbal cognitive abilities (Arick, Krug, Fullerton, Loos, & Falco, 2005).

In contrast, perceptual or fluid cognitive abilities do not rely on verbal comprehension or verbal output. Spatial awareness, visual processing, perceptual organization and reasoning, and visual-spatial problem solving are abilities central to the construct of perceptual/performance IQ (Sattler, 2008). Anecdotal reports have suggested that individuals with Autistic disorder actually think visually rather than verbally (Grandin, 1995). Thus, it would be expected that individuals with Autistic disorder perform better on visual-spatial cognitive tasks.

The claim that children with Autistic disorder have higher Performance/Perceptual IQ (PIQ) than Verbal IQ (VIQ) was first postulated by Lockyear and Rutter (1970). They found a statistically significant difference between PIQ and VIQ in a sample of 19 children with Autistic disorder on the Wechsler Intelligence Scale for Children (Wechsler, 1949). The highest subtest score was on Block Design, a measure of visual-perceptual organization and reasoning, and the lowest subtest score was on Comprehension, a measure of social judgment and problem solving. As of 2000, these findings were generally replicated by 20 other studies with over 500 children and adolescents with Autistic Disorder, all of different ages and ability levels (Barnill, Hagiwara, Myles, & Simpson, 2000).

Most recently, Mayes and Calhoun (2003b) found that the difference between perceptual and verbal IQ was statistically significant only for children younger than six years. The difference was not statistically significant for children older than six years. Thus, they suggested that the difference between perceptual and verbal abilities closes during school-aged years, particularly for children who received early intervention (2003a). Dyck et al. (2007) found that Performance IQ exceeded Verbal IQ on the Wechsler Intelligence Scales for Children, Revised [WISC-R] (Wechsler, 1974) in 52% of 29 children with Autistic disorder. This is a lower percentage difference than most reported studies. Mayes and Calhoun (2008), using the most updated child Wechsler assessment, the Wechsler Intelligence Scale for Children, 4th Edition [WISC-IV] (Wechsler, 2003), found that the Perceptual Reasoning Index was statistically significantly higher than the Verbal Comprehension Index in their sample of 54 children. Similar to research conducted 40 years ago, children with Autistic disorder earned the highest score on Block Design and the lowest score on Comprehension. Finally, Charman et al. (2011) assessed 156 children using the Wechsler Intelligence Scale for Children, 3rd Edition [WISC-III] (Wechsler, 1991) and found a small significant difference between VIQ and PIQ. Their sample confirmed the newer belief that about one half of those diagnosed with an ASD have an IQ below 70. The authors also found that about 25% of the sample had an FSIQ in the average or above average range.

The sparse research on cognitive abilities in PDD-NOS suggests that the cognitive profile of Autistic disorder is fairly common in PDD-NOS as well (Dawson et al., 2002). A wide range of intellectual quotients have been documented in PDD-NOS. Further,

children with PDD-NOS tend to perform better on visual and perceptual tasks (such as Block Design), as opposed to verbal tasks (such as Comprehension), on traditional IQ tests (Koyama & Kurita, 2008). This is the more commonly observed cognitive profile in Autistic disorder. However, given that extremely few research studies have specifically examined the cognitive profile of those diagnosed with PDD-NOS, generalizations about their cognitive abilities should be made cautiously.

While an uneven cognitive profile for individuals with Autistic disorder has emerged, the same cannot be said for individuals with Asperger syndrome. Recent work has turned to determining the cognitive profile of Asperger syndrome and whether cognitive assessments can differentiate those with Autistic disorder from those with Asperger syndrome. Although a range of IQ scores from below average to highly superior have been identified in people with Asperger syndrome, studies of group means point to average intelligence in the population (an IQ between 85 and 115) (Barnhill et al., 2000; Ghaziuddin & Mountain-Kimchi, 2004).

Original cognitive ability studies in children and adolescents with Asperger syndrome indicated that verbal abilities were significantly stronger than perceptual abilities, a reversal of the profile observed in children with Autistic disorder (Ozonoff, Rogers, & Pennington, 1991). Given the diagnostic criteria of no language delay and stronger verbal engagement in Asperger syndrome, the hypothesis that verbal ability would be better in those with Asperger syndrome than in those with Autistic disorder was initially well received.

Recent work has failed to replicate the Ozonoff et al. findings. In a study with 37 children with Asperger syndrome, Barnill et al. (2000) found no significant difference between performance ability and verbal ability on the Wechsler Intelligence Scales for Children, 3rd Edition [WISC-III] (Wechsler, 1991). Participants performed best on Block Design, with poor performance on Digit Span. This does not match the profile observed in Autistic disorder of strengths in Block Design and weaknesses in Comprehension. This finding was echoed in a study in which the difference between performance and verbal cognitive ability on the WISC-R was less than two points for 21 children with Asperger syndrome (Griswold, Barnhill, Myles, Hagiwara & Simpson, 2002). Conversely, in a group of 22 males with Asperger syndrome, a significant 10 point difference was observed between performance and verbal IQ on the WISC-III (Ghazuiddin & Mountain-Kimchi, 2004).

In an important caveat to the studies examining cognitive abilities in children with Autistic disorder, Dyck et al. (2007) noted that a number of studies examining IQ in children and adolescents with Autistic disorder have limited the participant samples to those with an IQ above 70, thereby ignoring a large subset of the population. Due to the inconsistent findings of cognitive ability in Asperger syndrome, they recommended avoiding using IQ tests as the basis for a diagnosis. Further, they argued that although it is possible to suggest that perceptual abilities are relatively stronger than verbal abilities in children with Autistic disorder when evaluating group means, individual differences are frequent, and thus a cognitive profile is not as useful for characterizing individuals with Autistic disorder as researchers and clinicians would hope.

Despite Dyck et al.'s (2007) argument, significant research has documented the uneven cognitive profile characteristic of children with Autistic disorder. While individual differences in cognitive abilities are expected, the most commonly observed cognitive profile for Autistic disorder is stronger performance on perceptual, spatial, or visual tasks. Tasks that require verbal mediation or abstract conceptualization seem to be more difficult. Although this profile has tentatively been documented in children with PDD-NOS, a cognitive profile characteristic of Asperger syndrome has not been identified. Early research pointed to a cognitive profile opposite of Autistic disorder, with verbal abilities stronger than nonverbal abilities. However, more recent work has generally found no differences in verbal and nonverbal abilities in children with Asperger syndrome.

Academic achievement profiles. Because general intelligence predicts between 35 and 50% of academic achievement abilities, cognitive profiles have been used to better understand the academic abilities in children and adolescents with Autism Spectrum diagnoses (Minshew, Goldstein, Taylor, & Siegel, 1994; Mayes & Calhoun, 2003a). Thus, it has been suggested that a combined cognitive and academic profile may be more useful for aiding in diagnosis and intervention development than the use of a cognitive profile alone (Mayes & Calhoun, 2008).

Within Autistic disorder, academic achievement has consistently found to be commensurate with IQ. IQ scores are predictive of academic achievement in that those with lower IQ scores have lower achievement scores and those with higher IQ scores have higher achievement scores (Jones et al., 2009; Mayes & Calhoun, 2008). Minshew

et al. (2004) noted that children with Autistic disorder and an IQ above 70 performed equally as well as control participants on mechanical reading, spelling, and computational tasks. However, they performed worse on comprehension tasks, including reading comprehension, math word problems, and written expression. The authors claimed that the achievement profile was reflective of the cognitive profile in that attention, rote memory, and basic language skills were intact, but pragmatic language, abstract reasoning, and complex memory were impaired.

In the Jones et al. study, 72.6% of participants had at least one achievement area that was significantly different from their Full Scale IQ (FSIQ). Sixteen percent of the sample showed an arithmetic “peak” with an arithmetic standardized score 14 or more points above their FSIQ, while six percent had an arithmetic score of 14 or more points below their FSIQ. A reading peak occurred in 14% of the sample and a reading trough in 10% of the sample. Further, these participants with discrepant achievement scores were in mutually exclusive groups. Those with a reading peak did not have a math peak or trough and vice versa.

Mayes and Calhoun repeatedly found that academic achievement was relatively uniform across participants. In a series of studies in 2003, they found that math achievement was significantly lower than reading, writing, and spelling, but only for participants with an IQ less than 80. The other academic achievement areas were not significantly different from each other. In their most recent study (2008), they found that Written Expression on the Wechsler Individual Achievement Test [WIAT] (Wechsler, 1992) was the lowest area of academic achievement and was significantly different from

all other achievement areas. No other achievement areas were found to be significantly different from each other, and no significant differences were found between reading or math scores and FSIQ.

No studies examining academic achievement with PDD-NOS as a distinct diagnostic entity have been identified. Therefore, any information about the academic abilities of those with PDD-NOS is based on generalizations from the Autistic disorder literature (Loveland & Tunali-Kotoski, 2005).

While children and adolescents with Asperger syndrome generally have average to above average intelligence, they often struggle academically (Minshew et al., 2005). Academic tasks that seem to be easier for children and adolescents with Asperger syndrome are comprehension of factual material, rote memorization, and calculation. Common areas of struggle include comprehension of abstract concepts, problem solving, determining relevancy of information, and application of information to real-world situations (Hagiwara, 2002).

Overall, in the few studies examining academic achievement in Asperger syndrome, math and listening comprehension have typically been the lowest areas of academic achievement and reading has been the highest overall achievement area. However, Griswold et al., (2002) found that when academic tasks are grouped into comprehensive means, rather than broken down by task, children with Asperger syndrome appear to be functioning within normal limits. For example, the mean Reading Comprehension score on the Wechsler Individual Academic Test (WIAT) was 101.7. However, participants scored eight points higher on Basic Reading than on Reading

Comprehension. Similarly, on Math Comprehension, the overall score was 91.76, with a non-significant seven point difference between Math Reasoning (96.9) and Numerical Operations (89.8).

Given the current state of diagnostic conceptualizations, academic profiling may be more useful for children and adolescents with Autistic disorder than those with Asperger syndrome. Students with Autistic disorder typically present with even academic profiles that are commensurate with their IQs. However, students with Asperger syndrome present with highly varied academic profiles, even within core academic areas. Similar to IQ scores, individual scores vary greatly within a study sample; researchers advocate for the use of specific content area scores, rather than overall achievement means, when developing an academic profile. Research on academic achievement in ASDs is less prolific and less conclusive than research on cognitive ability. In general, it can be concluded that the majority of individuals with an ASD will have difficulty in at least one academic area. Further, abstract concepts and higher-order complex thinking prove more problematic than rote memorization and factual information.

Other Psycho-educational Constructs

While cognitive ability and academic achievement are the most common constructs associated with learning and education, other neuropsychological constructs such as attention and language represent domains that contribute to a behavioral phenotype and affect daily activities, especially the ability to learn. Students with ASDs show unique strengths and deficits across a multitude of domain-specific psycho-

educational constructs (Loveland & Tunali-Kotoski, 2005). Exhibition of varying strengths in these constructs can also help in the identification of phenotypic profiles.

Attention. Attention is a broad term used to describe the general ability to recognize and concentrate on a specific sensory perception. Anderson and colleagues developed a four factor model of attention: sustained (maintaining vigilance over extended periods of time), focused (attending to one stimulus while ignoring irrelevant, extraneous stimuli), divided (attending to multiple stimuli at once), and response inhibition (a form of controlled attention) (Anderson, Fenwick, Manly, & Robertson, 1998). These attentional types are necessary for most aspects of daily living, and are especially important for learning. Research has shown that students with attention problems have lower academic outcomes later in their schooling, along with more pronounced behavioral and social difficulties (Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010).

Although research on attention as it relates to cognitive and academic functioning in students across all ASDs is sparse, there is growing consensus that such individuals may display a specific attentional profile. That is, research is suggesting that these students have specific strengths and deficits based on attention type, and that this profile can help aid in the development of interventions (Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). However, attention research is complicated by the fact that attention ability is also thought to be related to sensory perception preference. A student with strong visual sensory preference and auditory sensory aversion will likely show better attention skills for visual input and poor auditory attention skills (Tstatsanis, 2005).

Further, many studies examining attention in individuals with ASDs have used controlled laboratory designs and simple sensory perception tasks. It is difficult to know if the results of these studies are ecologically valid. Applied settings such as classrooms require increased synthesis of multiple information sources simultaneously. Thus, attention may be more severely compromised in classrooms than in laboratories.

Sustained attention is the most common type of attention associated with academic learning. It is generally preserved in Autistic disorder, but found to be a deficit in Asperger syndrome, particularly for simple visual information (Goldstein, Johnson & Minshew, 2001; Sanders, Johnson, Garavan, Gill, & Gallagher, 2008). For some individuals with Autistic disorder, this ability translates into an overly intense focus on particular objects or unusual parts of objects. Thus, while the sustained attention mechanism itself is preserved, this preservation can lead to other unfavorable characteristics. Individuals with Asperger syndrome do not show the same sustained attention capabilities. Rather, they are unable to maintain focused and directed attention for long periods of time, particularly in the classroom (Schatz, Weimer & Trauner, 2002). Similar to research on achievement, no research examining attention abilities in students with PDD-NOS exists. It is presumed that their attention abilities are similar to those with Autistic disorder.

Difficulties with focused (selective) and orienting attention are evidenced by the tendency to focus on non-salient or unimportant aspects of the environment and the poor ability to shift attention both between and within sensory modalities (Tstatsanis, 2005). Focused attention, in which an individual actively chooses the information he/she attends

to, and orienting attention, the ability to disengage from one stimulus to focus on another, are closely related. These types of attention are also important in academic learning, as students must be able to filter multimodal sensory information to determine what to pay attention to in the classroom. Early studies showed that people with Autistic disorder had impaired focused attention, as shown by difficulty attending to a target with the presence of visual distracters (Burack, 1994; Garretson, Fein, & Waterhouse, 1990). However, as previously noted, these studies used simple computer-based response tasks in laboratory settings. Divided attention, the ability to pay attention to two or more different sets of information at once, is suggested to be another area of weakness for individuals with ASDs, although limited research examining divided attention exists.

Overall, the presentation of attention abilities in ASDs is not clear; results regarding the attentional profile of these students are mixed (Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001). It is generally accepted that sustained attention is intact for students with Autistic disorder and that focused/selective and orienting attention are not as strong. The extent to which attentional skills interferes with learning depends on a multitude of other factors, including sensory preference and IQ. Despite the lack of a definite attention profile, it is known that attentional deficits do lead to decreased academic achievement (Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010). As Burack (1994) stated “persons with autism are unable to attend efficiently to the most relevant information in the environment and therefore do not effectively learn from and relate to their surroundings” (p. 542).

Language and communication. Deficits in language and communication are one of the major triad of symptoms associated with ASDs. The literature on these deficits is extensive, and will only be briefly summarized here to provide a general overview of how language profiles may aid in the development of more specified phenotypes of ASDs. More than one half of students with Autistic disorder fail to develop verbal language (Wahlberg, 2001). Language ability is a major predictor of positive outcomes for children with ASDs (Lord et al., 2005). The presence of early language is associated with better behavioral, academic, and social outcomes. Cognitive ability has been found to be the most significant predictor of the development of verbal skills in children with ASDs (Kjellmer, Hedvall, Fernell, Gillberg, & Norrelgren, 2012). In individuals who do develop language, the ability remains reflective of difficulties with social interactions. That is, despite the presence of language, these students still have difficulty using language effectively and appropriately.

An extensive list of negative language characteristics in ASD has been identified, including echolalia, avoidance of personal pronouns, incorrect pragmatics, inappropriate intonation, prosody and voice modulation, idiosyncratic and repetitive speech, and pedantic and formal speech (Loveland & Tunali-Kotoski, 2005). These characteristics have been identified in classic Autistic disorder, Asperger syndrome, and PDD-NOS to varying degrees. Non-verbal communication in typical populations includes the use of eye contact, gestures, facial expressions, and gaze following. Yet, most of these communication methods are impaired in individuals with ASDs. Tager-Flusberg and Joseph (2003) identified two language phenotypes in children with ASDs that have some

language capabilities: typical language abilities and specific language impairment. The authors, however, noted that there are likely other language phenotypes on the autism spectrum. Because of its critical importance to academic and other outcomes, language ability should be considered extensively when developing a behavioral phenotype.

Sensory perception. Abnormal response to sensory input has long been documented as a primary area of difference in children with Autistic disorder; it has been found to differentiate children with Autistic disorder from children with other developmental disabilities (Osterling & Dawson, 1994). Abnormal response is reflected in behavior upon sensory input. Both hypersensitivity and hyposensitivity across all five senses have been documented in individuals with Autistic disorder (Tstatsanis, 2005). For example, the commonly observed behaviors of hand flapping or spinning are thought to be reflective of a need for proprioceptive stimulus. Behaviors such as visual interest in moving objects or constant viewing of parts of objects are thought to indicate a preference for visual input, whereas hypersensitivity to sound has been interpreted as a dislike of auditory input (Stone, 1997). Sensory abnormalities affect attention and behavior which, in turn, can negatively affect the capacity to learn in the classroom. Sensory abnormalities in both PDD-NOS and Asperger syndrome seem to be less significant, but there is not enough research to draw definitive conclusions about the degree of the role sensory difficulties play in these two disorders (Tstatsanis).

Social and adaptive behavior. As described in the *DSM-IV-TR* diagnosis of Autistic disorder, Asperger syndrome, and PDD-NOS, one of the hallmark deficits of ASDs is in social behavior and social understanding. These deficits negatively affect the

adaptive behavior of students with ASDs. Wing and Atwood (1987) identified three subtypes of social behavior that characterize individuals with ASDs. Students with classic Autistic disorder are typically considered “aloof.” They have no interest in social contact with people, actively avoid social situations, and can become distraught if forced into such situations. They have few or no social relationships with adults or other children, and rarely engage in any verbal or nonverbal communication. The “passive” children are those who lack skills needed for social interaction, but do not actively avoid it. They tend to exhibit stereotyped behaviors and have language difficulties. Some have associated these children with the PDD-NOS DSM-IV diagnostic category. Finally, the “active-but-odd” children commonly describe students with Asperger syndrome or High Functioning Autism. They have difficulty relating to peers because of odd communication and behavior mannerisms, but actively seek out engagement.

Adaptive skills have been found to be closely related to overall intellectual ability. This is especially true for children who are lower functioning. Conversely, the adaptive behaviors of higher functioning children are more closely related to verbal and language ability alone (Liss et al., 2001). Kenworthy and colleagues (2010) found that socialization is the most significantly impaired adaptive ability in those with ASDs. Further, lower IQ and increased severity of autism symptoms were related to lower overall adaptive abilities. Maladaptive and self-injurious behaviors are another common characteristic of Autistic disorder. While individuals with milder ASDs such as Asperger syndrome and PDD-NOS may exhibit maladaptive behaviors, more research has been conducted for Autistic disorder. Maladaptive behaviors are generally associated with repetitive,

stereotyped behaviors such as hand wringing or flapping, spinning, or touching of objects. However, many maladaptive behaviors are exhibited for avoidance or escape purposes. Such behaviors may include tantruming, running away, hitting, kicking, yelling, and biting. Other behaviors are self-injurious, such as scratching or head banging, and involve harm to the individual due to sensory needs or coping methods.

Rather than focus on one particular domain when evaluating outcomes, it has been suggested that multiple phenotypic domains be examined (Moss & Howlin, 2009). The above constructs are not comprehensive of all possible components of ASD phenotypes. They represent a select set of constructs that are more pertinent to learning and typically evaluated through standardized measures in educational settings. Cognitive profiles and achievement profiles are two of the most important domains to consider when evaluating response to academic interventions, but a comprehensive behavioral phenotype should be developed. By examining the relationship between intervention outcomes and multiple phenotypic domains, interventions can be tailored more specifically to individuals.

Autism Spectrum Disorders and Education Law

As of 2008 (the last available year count), 337,572 children and adolescents from age 3 to age 21 with an ASD diagnosis were served in special education in the United States. This represents over a 500% increase in the past 15 years, making the Autism diagnostic category the fastest growing category in special education. Students with an ASD are the fifth largest group of special education students in the country, with an annual cost of \$18,000 per student (IDEAdata.org, 2010). Further, these numbers do not

include students with an ASD who receive only general education services, or students with an ASD who are labeled under a different category within special education, such as Speech/Language or Multiple Disabilities.

The provision of special education services to children with an ASD is clearly delineated in the Individuals with Disabilities Education Improvement Act (IDEIA) of 2004 (Public Law 108-446). IDEIA provides the legal guidelines for assessment, services, and funding for children with disabilities in the country's special education programs. The original purpose of IDEIA (previously the Education of All Handicapped Children Act, [EAHCA] 1975) was to ensure a fair and appropriate education for students with disabilities and to protect the rights of these students and their parents by providing federal funding for schools that complied with EAHCA. Changes to IDEIA 2004 from previous versions of the law were made to alter the low academic expectations previously held for students with disabilities and to ensure the use of scientifically-based instructional and intervention methods in special education, essentially aligning IDEIA with Public Law 107-110, No Child Left Behind.

Autism is one of 14 categories within IDEIA (2004) in which students may qualify for special education. It was added to the law in 1990. The law states that a student will not qualify for special education if his/her educational performance is not adversely affected. The current IDEIA definition of autism is:

A developmental disability significantly affecting verbal and nonverbal communication and social interaction, generally evident before age three, that adversely affects a child's educational performance. Other characteristics often associated with autism are engagement in repetitive activities and stereotyped movements, resistance to environmental change or change in daily routines, and unusual responses to sensory experiences. (300.8 c.1.i)

While a majority of students with an ASD are served in special education, having such a diagnosis does not exempt them from the academic standards to which all students in the country are held. Public Law 107-110, also called No Child Left Behind (NCLB), was authorized in 2001. No Child Left Behind is a reauthorization of the Elementary and Secondary Education Act (ESEA) of 1965. The original purpose of ESEA was to identify and financially support schools that served economically disadvantaged children. In 1983, the National Commission on Excellence in Education wrote the *A Nation at Risk* report; the report was extremely critical of America's educational system. Students were failing to achieve commensurate levels in reading and math as those in other developed nations. Disadvantaged students were faring even worse, and federal education funds were not being appropriately spent to improve academic achievement of students in the United States. Thus, the *A Nation at Risk* report became the cornerstone of two subsequent reauthorizations of the ESEA, leading to significant educational reform, the Improving America's Schools Act (1994) and ultimately, No Child Left Behind (2001).

No Child Left Behind (2001) was designed to ensure that all students achieve state educational learning standards when taught by highly-qualified teachers in safe classrooms. All students are held to the same academic standards, thereby closing the achievement gap that exists for students of racial and ethnic minority status and students with disabilities. NCLB mandates that all students reach proficiency in reading and writing by 2013-2014 and that all students graduate high school. Schools and districts are held accountable for reporting progress towards proficiency and for implementing evidence-based instructional methods to ensure proficiency is reached.

IDEIA (2004) and NCLB (2001) have significant implications for students with disabilities, including those with ASDs. NCLB mandates that students with disabilities are to be held to the same age or grade academic standards as their typically developing peers. Students with disabilities are required to take either standardized state assessments or alternate state assessments, and districts are required to report the proficiency level of the majority of these students. This prevents school districts from ignoring the academic progress of students with disabilities and districts are thus held accountable for the students' achievement. Similarly, one overarching purpose of IDEIA is:

(i) to improve the academic achievement of children with disabilities and their performance on regular statewide assessments as compared to nondisabled children, and the performance of children with disabilities on alternate assessments (Section 663).

Also, IDEIA states that students with disabilities must have access to the general education curriculum and be educated in the least restrictive environment to the fullest extent possible, as another overarching purpose of IDEIA is:

(ii) to improve the participation of children with disabilities in the general education curriculum (Section 663).

Both NCLB and IDEIA require the use of evidence or scientifically-based instruction and intervention methods for all aspects of education: instruction, assessment, professional development, progress monitoring, and systems management. Thus, schools should not use untested and unreliable educational methods. The NCLB definition of scientifically-based research is: “research that applies rigorous, systematic, and objective procedures to obtain relevant knowledge” (NCLB, 2001, 20 USC 1208(6)). ‘Evidence-based’ or ‘scientifically-based’ signifies that research has been conducted to evaluate the

method of interest. Research evaluation may stem from an evaluation of a methods' efficacy through fully controlled experimental designs. Or, the effectiveness of a method has been examined through multiple partially controlled experimental designs or single-case research studies. The What Works Clearinghouse (WWC) was developed in 2002 to provide educators with a database of instructional methods that pass strict criteria and are considered to be highly research-based. A multitude of information also exists about educational programs and instructional methods that, although have not met the strict criteria delineated by the WWC, have partial support for effectiveness (Kazdin, 2004).

Together, these laws support the notion that students with disabilities cannot be ignored in schools' efforts to increase academic achievement. Such students are to be held to the same achievement standards and generally participate in the same achievement assessments. Further, general education and special education instruction and intervention must be based on empirical research validation. Because the most recent reauthorization of IDEIA was aligned with NCLB, the two laws work in concert to ensure the education of children with disabilities, including those with autism.

Evidence-Based Instruction and Autism Spectrum Disorders

A prolific amount of time and money has been dedicated to developing and evaluating educational practices and interventions for ASDs. Because of the sheer number of interventions and treatments purported to be effective for children with ASDs, the National Research Council formed the Committee on Educational Interventions for Children with Autism to determine what interventions, or components of interventions, contribute to the success of children with an ASD (2001). The report also details

diagnostic and assessment practices, examines the roles of families, considers the effect of public policies on ASD intervention, and advocates for ASD research standards. A number of recommendations across each of these areas were made based on a review of the scientific literature. It is important to note that the findings of this committee are based on early education, and thus are primarily relevant for children birth to eight years.

The Committee determined that the following areas should receive priority intervention in early and school-age education: functional and spontaneous communication, social interaction, play, general cognitive development, problem behaviors, and functional academics (2001). The Committee did not endorse specific or commercial interventions. The NRC's recommendations for intervention areas primarily focused on the deficits associated with language and communication and social behavior. Although the Committee recommended interventions be in place for functional academics, essentially no information was provided regarding best practices in academic instruction for students with ASDs.

Further synthesis of the research regarding educational practices and students with ASDs led to the identification of components of interventions that were found to be most effective (Iovannone, Dunlap, Huber, & Kincaid, 2003). The authors reviewed comprehensive reports regarding the effectiveness of interventions for ASDs from 1992 to 2002. Based on their review of these reports, they identified six core components that are present in most or all interventions designated to be possibly efficacious or probably efficacious. The components identified by this research review are as follows:

1. Structured learning environment with predictability and routine
2. Family involvement

3. Early intervention
4. Specialized curricula focusing on communication and social interaction
5. Integrated classrooms
6. Functional approach to behavior
7. Planned transitions between classes and grades
8. Individualized, systematic, planned instruction

Similar to the NRC report (2001), there was not sufficient information regarding efficacy or effectiveness of academic interventions for students with ASDs in the literature. Therefore, the authors of the review could not make recommendations about academic learning.

Finally, the National Autism Center (2009) produced a comprehensive report on the specific interventions that have empirical support in educating children with ASDs. Of 38 interventions reviewed, 11 have established empirical support, 22 have emerging empirical support, and 6 have no empirical support. The majority of the established interventions involve behavior, communication, and social interaction. In fact, the report acknowledged that academic interventions of any kind have no solid evidence of improving outcomes for students with ASDs.

This finding has been echoed repeatedly in the multitude of text books designed to educate professionals on teaching children with autism (Jordan & Powell, 1995; Magnusen, 1995; Spencer & Simpson, 2009; Wahlberg, Obiakor, Burkhardt, & Rotatori, 2001). Comprehensive early intervention packages for ASDs have been studied extensively. Several programs have been determined to be possibly efficacious or empirically based, including Applied Behavior Analysis, pivotal response training, discrete trial training, and TEACCH (Rogers & Vismara, 2008). Although the benefits of such techniques to improve social skills and language and to decrease unwanted

behaviors are repeatedly emphasized, academic instruction and intervention is virtually ignored in ASD research.

In the small number of publications regarding fostering academic achievement in students with ASDs, reading is the primary focus. Given the nation's focus on improving reading outcomes for all students (National Reading Panel, 2000) this is not unexpected. However, the National Council of Teachers in Mathematics (NCTM) also developed a set of standards as a guide for educating children in mathematics (2000). The NCTM's *Principles and Standards for School Mathematics* recognized that all students should have the opportunity to learn math to a significant depth and breadth. Further, the Council believed that all students, when provided with high-quality instruction, can achieve in math. A set of five content standards in which all students should reach proficiency through a coherent, logical curriculum sequence were identified. The content standards are numbers and operations, geometry, algebra, measurement, and data analysis and probability. Based on these content standards, NCTM developed tools to aid in the development of specific math standards for each grade level. There have been no studies to date examining the applicability of the NCTM content standards to students with ASDs.

Math Achievement in Autism Spectrum Disorders

In 2007, Chiang and Lin reported that studies examining math achievement in both Autistic disorder and Asperger syndrome have been "very limited" (p. 548). They identified and reviewed a total of 18 studies published between 1986 and 2006 that specifically addressed mathematical ability in either one or both of these populations.

Studies that used standardized forms of assessment of math achievement were even scarcer, with only eight of the studies using standardized math achievement measures. The authors' general conclusion was that math ability in both Autistic disorder and Asperger syndrome falls in the below average to average range, with wide variability in individual differences.

One of the earliest studies examining math achievement in Autistic disorder found that children with Autistic disorder performed as well as typically developing children on rote computational tasks (addition, subtraction, etc.). However, the children with Autistic disorder performed significantly less well than typically developing controls on math problem solving tasks (Minshew et al., 1994). In a study with 100 adolescents with Autistic disorder, the Wechsler Objective Numerical Dimensions test was administered. The average Numerical Operations score was 85.9 and the average Math Reasoning score was 84, both on the low to below average cusp. Both achievement areas had large standard deviations, indicating large variability among participants. Further, 16% of the participants had a math achievement score that was 14 or more points higher than their FSIQ, while only 6.1% had a math achievement score that was 14 or more points lower. This indicated that although the achievement scores for math fell in the low to low-average range, most participants performed at or above expected math achievement level given their FSIQ (Jones et al., 2009). In two other recent studies that used the Wechsler Individual Test of Achievement, Math Comprehension was found to be similar to Reading Comprehension, and at the same level as the child's FSIQ (Mayes & Calhoun,

2008; Mayes & Calhoun 2003a). In all of these studies examining math achievement in Autistic disorder, the participants had full scale IQ scores higher than 70.

In a study with 21 children with Asperger syndrome (mean age of 10), Griswold et al. (2002) administered the Wechsler Individual Achievement Test. They found that Math Comprehension was the lowest area of academic achievement when compared to Reading, Writing, and Oral Language. The overall Math Comprehension score was 91.7, with a large standard deviation of 21.5. However, when Math Comprehension was broken down into two subcategories, Numerical Operations and Math Reasoning, participants performed better on Math Reasoning (96.9 versus 89.9). The authors suggested that students with Asperger syndrome will commonly show an achievement deficit in math and will need help with applying mathematical principles, understanding number functions, and performing accurate calculations.

Math interventions in Autism Spectrum Disorders. Even fewer studies have examined the efficacy of math interventions for children with ASDs. While some of the literature on math interventions has stemmed from research on globally grouped students with low-incidence disabilities and students with mild-to-moderate Intellectual Disability, only five studies were identified that examined math interventions specific to Autistic disorder (Banda, McAfee, Lee, & Kubina, 2007; Cihak & Foust, 2008; Cihak & Grim, 2008; Levingstone, Neef, & Cihon, 2009; Rockwell, Griffin, & Jones, 2011). None were identified specific to Asperger syndrome. These four studies used single-case research designs, and most focused on functional math or basic computational skills.

Banda et al. (2007) examined whether having mastery over a type of math problem (digit facts or word problems) increased five middle school students' preference for that type of problem. They found a weak relationship between mastery and task type, with most students choosing to solve digit facts regardless of mastery. This study addressed a motivational strategy more so than an actual math intervention.

Barnhill et al. (2000) suggested that mental math is difficult for students with Autistic disorder and Asperger syndrome because of the lack of visual supports. This was echoed in Magnusen (2005) who suggested that instruction in general for students with ASDs should rely on visual and/or multimodal sensory instructional techniques. Based on this theory, Cihak and Foust (2008) compared whether the use of a number line (simple visual representation) or the use of touch point math (e.g., Touch Math, a multi-model sensory technique) increased simple addition calculation ability. Using single case design, they found that touch points (physically touching components of each numeral) was more effective at increasing simple addition skills, and was the preferred method of learning for three elementary students with Autistic disorder.

Counting-on, a strategy most children acquire by first grade, involves addition of a given amount based on the value of a second number. That is, rather than representing $5+2$ as $1 + 1 + 1 + 1 + 1 + 1 + 1$, students learn the importance of using the numerical value of five to add two more, with an end result of seven. In an attempt to teach four students with Autistic disorder purchasing skills, authors of another study used explicit instruction of the counting-on strategy. The authors concluded that when provided with

systematic, direct strategy instruction, students with Autistic disorder can learn more complex mathematical skills (Cihak & Grim, 2008).

Levingstone et al. (2009) used principles associated with pre-teaching to increase the math word problem solving ability of one elementary school student with Autistic disorder and one typically developing student. Word problems are known to be quite difficult for students with ASDs because of the reliance on verbal mediation and the necessity of identifying salient concepts from non-salient concepts in the problem. The authors found that the pre-teaching strategy was effective in increasing the number of word problems both students correctly solved. The strategy was not necessarily more beneficial for the student with Autistic disorder.

Rockwell and colleagues (2011) used schema-based strategy instruction to teach addition and subtraction word problems to a fourth grade student with Autistic disorder. The student's cognitive ability was in the Low range (FSIQ=79) and his achievement standard score was 63, which is in the Very Low range. Using multiple-probe single case design, the authors found that the student's ability to solve basic word problems increased following schema-based instruction.

The scant research on effective math interventions for ASD is in direct contrast with federal law, which states that students with ASDs must have access to the general curriculum and be taught with evidence-based instructional methods. Cihak and Foust (2008) noted that "there is a growing need to teach general curriculum academics to students with moderate and severe disabilities, including autism, effectively" (p. 718). Mathematics is one of the most neglected areas of academic achievement and academic

interventions, not just for students with ASD, but for students with disabilities in general. There is a desperate need for further research on effective ways to teach math to students with ASDs.

Computer-Assisted Instruction

A specific type of intervention has garnered recent support as a potentially evidence-based intervention for students with ASDs: Computer-Assisted Instruction (CAI). An early review of the use of CAI with students with Autistic disorder suggested that discrete skills can be taught via the computer (Panyan, 1984). CAI is becoming a commonly used method to teach students with ASDs communication skills (Sansosti & Powell-Smith, 2008), social problem solving (Bernard-Opitz, Sriram, & Nakhoda-Sapuan, 2001), and social skills (Simpson, Langone, & Ayres, 2004). However, the application of CAI to academics has been less common (Pennington, 2010).

Academically, CAI has most readily been applied to increasing reading skills for children with ASDs. In an early study of reading and CAI, children with autism increased scores on reading and communication measures by 16% during CAI. However, their learning leveled off when CAI was suspended, suggesting that learning did not generalize beyond the use of the computer (Heimann, Nelson, Tjus, & Gillber, 1995). Using single-case design, Williams and colleagues (2002) found that five out of eight children with Autistic disorder could identify more words after implementation of CAI. More recently, it was reported that CAI is an effective mechanism to deliver the nonverbal reading approach. A student with severe Autistic disorder was able to correctly identify words

80% of the time in both teacher-led instruction and CAI (Coleman-Martin, Heller, Cihak, & Irvine, 2005).

Although a review of the literature did not result in the identification of any studies using CAI to teach math skills for children with ASD, one study did use CAI to teach math word problem solving skills to children with Intellectual Disability (Jaspers & van Lieshout, 1994). The goal of the computer program was to teach students to identify key words in math word problems to aid in problem solving; three variations of the program were used. Because the authors did not compare the students who received CAI to students who did not receive CAI, no claims could be made about the effectiveness of CAI over personal instruction. They did find that targeting different components of the intervention led to differential skills in the children. Similarly, a recent meta-analysis of the use of math CAI for students with a math learning disability found mixed results for the effectiveness of CAI (Seo & Bryant, 2009).

CAI has been found to increase attention and engaged academic time of students with ASDs (Chen & Bernard-Opitz, 1993). It has also been found to increase behavioral compliance by both reducing negative behaviors and increasing positive behaviors. The reasons for this increase in positive behavioral outcomes are unclear. Several explanations have been proffered, ranging from minimal peripheral distractions to increased motivation and interest in computers to less social interaction demands (Bolte, Golan, Goodwin, & Zwaigenbaum, 2010; Panyan, 1984).

Chen and Bernard-Opitz (1993) compared CAI and personal instruction for academic skills, attention, and compliance in four students with autism. Although

students showed more enthusiasm and better compliance while learning via the computer, only one student showed clear academic gains from CAI. Academic skills assessed in this study were dependent on the individual participant's need. This is in contrast to a 1990 study by Bernard-Optiz in which six of seven students showed that CAI led to increased learning more so than personal instruction.

Jordan (as cited in Chen & Bernard-Optiz, 1993) suggested the following reasons as benefits of CAI when educating students with an ASD:

1. Consistency and regularity
2. Continuous availability and on demand stimulation without making return social demands on the child
3. Practice and sufficient overtraining
4. Multiple input/output devices can be adapted to the needs of the child

Computer-based learning programs can be designed to provide the exact same stimuli and response requirement for every learning opportunity, thereby making the interaction between student and program consistent and structured. Given students' with ASDs need for predictability and structured routine, CAI can potentially serve as a more structured instructional method than teacher-led instruction. Further, students do not need to rely on an adult to provide frequent attention and feedback. Rather, as long as students are permitted to engage in the program, they will receive ongoing reinforcement from a stimulus in close proximity. Computer programs also allow for massed practice. By not moving forward in instruction until a skill has been learned, students will be provided with as much practice as necessary to learn the skill. Finally, the sensory needs of individual students can be accounted for by modifying how the student receives information and how the student provides input (Siegel, 2003).

Despite the numerous potential benefits in the use of CAI for students with autism, CAI is not a widely-adopted instructional intervention. While interest in CAI as a behavioral and social intervention is growing, the use of CAI as an academic intervention, particularly for math, remains limited. In the era of school reform, accountability, and scientifically-based instruction, research is needed to determine if CAI is truly an effective means to teach students with ASDs behavioral, social, and academic skills.

Spatial-Temporal Math

Spatial-Temporal Math (ST Math) is a computerized non-verbal instructional program designed by the MIND Research Institute to increase mathematical achievement skills in school-aged children (2010). It was originally designed to be an instructional supplement to any given math curriculum. The basic premise of ST Math is that students can initially be taught fundamental math concepts without reliance on language, terminology, or symbols. Thus, students learn early math concepts through pictorial images by completing simple puzzles or problems. The goal of every problem is to move an animated character (Jiji, a penguin) across the computer screen. As students master fundamental concepts, symbols and math terminology are introduced in conjunction with visual representations. All graphics are relatively simple, decreasing peripheral distractions on the screen.

The content of ST Math is in alignment with curriculum based standards. Specifically, ST Math is based on state core standards, forming a “national core curriculum” (Personal communication, 1/2011). The program begins with math concepts

that are typical of a Kindergarten level and is leveled to address standards for each grade level up through grade 5. There are subsequent programs for middle and high school levels (ST Math Secondary Intervention and Algebra Readiness).

Each grade level has 15 to 24 different objectives that teach content aligned with developmental math standards. Within each objective, there are different levels that correspond to different games that students can play. Each game for each objective has two stages: training and applying. The training stage provides examples of the problems students will encounter in the particular game. Students play the game, but are shown the correct answer prior to playing. The application stage is the stage at which students' ability is monitored. Each game has the same characteristics: 1. for each question there is only one correct answer out of three or four choices, 2. there is no penalty for incorrect responses, 3. visual feedback is provided and indicates whether or not a response is correct, and why it is, 4. for each question, the student is allowed as many attempts as necessary, and 5. for each attempt at a given question, the answer choices and the order of choices remains the same.

The program monitors several aspects of learning. This monitoring occurs in real time, and thus allows teachers to provide immediate assistance. On higher level objectives for higher grades (such as fractions in fifth grade), the program implements a pre-quiz. The pre-quiz tailors introductory questions to ability level, and is then compared to the post-quiz for the objective. Within each game, time on task, number of tries, and correct and incorrect responses are measured. Further, standard mastery is monitored for all grade levels. Standard mastery is calculated based on an algorithm that takes into

account post-quiz scores, total number of attempts, and amount of grade level standard covered by objectives played thus far.

A number of evidence-based instructional techniques are embedded in ST Math. Grade content is designed to address standards associated with that grade. Further, within each grade level, problems in any given content area are graduated in difficulty level. Thus, students must first master simpler skills and problems before gaining access to more difficult problems and higher level skills. Activating and using prior knowledge to solve problems is one of seven instructional techniques identified by Gravois and Gickling (2008) as essential to learning. The program automatically encourages activation of prior mathematical knowledge by requiring the use of lower level skills to solve higher level problems.

Further, beginning with simple problems allows for immediate success. Mastering simple problems and skills allows for appropriately graduated instruction. Thus, the student's instructional level will be correctly targeted. Working at an appropriate instructional level is an empirically-based instructional strategy; it allows a student to feel some success and some challenge (Burns, VanDerHeyden, & Boice, 2008; Gravois & Gickling, 2008). Both of these instructional techniques (initial success and scaffolding) have been shown to be effective methods of teaching.

The ST Math program provides immediate corrective feedback after each problem. Regardless if the problem was answered correctly or incorrectly, a re-animation of the problem occurs. This is done to either show the student that he/she answered correctly or to show the correct solution if answered incorrectly. After reviewing studies

on academic instruction, Burns et al. reported that appropriate corrective feedback is an empirically-based instructional technique (2008). During skill acquisition (the earliest stage of learning), a student should be provided with immediate feedback on his/her performance.

ST Math is self-paced. Students can take as much time as they need on a problem, level, or objective. Further, data collected by the program shows how much time a student spends on a problem, which can alert teachers to potential confusion. Self-pacing is important for students because it ensures that students do not fall far behind their peers and allows them to feel successful no matter the length of time it takes to respond.

Along with self-pacing is extensive use of repetition and high opportunity to respond. Students can have as many attempts as needed to master an objective in ST Math. Burns et al. (2008) found that increasing the number of presentations when rehearsing new items leads to increased retention of newly learned items, particularly for students with disabilities. They also reported that in comparisons of various instructional approaches (including CAI), increased opportunity to respond was the causal mechanism for learning. Repetition allows for the development of automaticity, an instructional technique identified by Gravois and Gickling (2008). Further, there is only one outcome for a correct response: moving the penguin across the screen. This provides consistency as to the purpose of each game or task.

These instructional techniques have been identified as empirically-based for typical students and/or students with disabilities. With its reliance on self-pacing, corrective feedback, and graduated instruction, ST Math advances learning through

curriculum objectives and standards. The program's focus on standards and achievement outcomes is in line with No Child Left Behind and the call for standards-based educational reform.

ST Math efficacy and effectiveness. The original ST Math program (ST Math Video Game) was designed in the mid-1990s. The software was initially studied in conjunction with music training to teach second graders fractions and proportional math (Graziano, Peterson, & Shaw, 1999). Five second-grade classrooms in one school in Los Angeles, California participated. One class received both music training and the ST Math Video Game, one class received typical math instruction and the ST Math Video Game, one class had random assignment of students between music and ST Math Video Game versus typical instruction and ST Math Video Game, and two classes conducted math instruction as usual. The students that received ST Math Video Game (whether in conjunction with music training or typical instruction) outperformed students on the ST Math Video Game evaluation who did not receive ST Math Video Game by 100%. However, this study did not implement true random assignment and some students received varying levels of instruction due to late entrance into the program. Further, outcomes were assessed by performance on the program, as opposed to performance on some alternate measure not associated with the ST Math Video Game (such as standardized state assessments or class-wide assessments).

The ST Math program undergoes frequent revision based on feedback from users and data collected from previous research studies (Hu, Bodner, Jones, Peterson, & Shaw, 2004). The implementation of ST Math increased from one school in 1998 to 40 schools

in 2005. During each year of the implementation, the MIND Research Institute team added more components to the software to address larger portions of the California mathematical curriculum standards. The team also modified other components of the software, including the computerized assessment, the performance feedback to students and teachers, and design elements.

In a review of the implementation of ST Math by the MIND Research Institute, it was reported that students who received any given version of the ST Math program showed increased mathematical achievement over students who did not receive ST Math. These gains were reported for students who received ST Math either in conjunction with music training or alone. Performance was measured by the ST Math post-test or the California state assessments, the Stanford 9 Mathematics Test or the California Achievement Test (Martinez et al., 2008).

Upon increase in the breadth of mathematical content, the ST Math Video Game evolved into the ST Animation Reasoning (STAR) software. One particularly challenging game in this software revision was studied with elementary and middle school students across different schools (Peterson et al., 2004). The authors found that students in both low and high socioeconomic schools who struggled with typical language-based math instruction and assessment performed better on the STAR game than on everyday math assessments. It was noted that “every child had substantial improvement independent of age, gender, or background including language-based math performance” (p. 7).

By 2005, the ST Math program had generally evolved into the program that is being used in the current study (Martinez et al., 2008). A large scale randomized control

trial of the most updated version of ST Math is currently underway in Orange County, California. The MIND Research Institute is collaborating with the Orange County School District to determine if ST Math leads to improved mathematical achievement. Underperforming schools in the district were randomly assigned to receive ST Math at two specific grade levels—either grades 2 and 3 or grades 4 and 5. The grade levels not implementing ST Math serve as controls. Thus, 18 “Cohort 1” schools are implementing ST Math in grades 2 and 3, but not in 4 or 5. Conversely, 16 “Cohort 2” schools are implementing ST Math in grades 4 and 5, but not in grades 2 or 3. Outcomes for all students in all four grades will be measured yearly by math scores on the California Standards Test (the California state assessment that all students in California must take). Further, five students per grade per school have randomly been selected to receive the Woodcock Johnson Tests of Achievement math tests.

To date, results are only available from the first year of the study (school year 2008-2009). Students who participated in ST Math showed an increase in math scores on the California Standards Test. There was a small-to-moderate effect size of .37 for ST Math (Rutherford et al., 2010). Information is not yet available on the Woodcock Johnson assessments.

Thus far, ST Math efficacy has been studied with typically developing students and English Language Learners. The use of ST Math for students with disabilities has been limited, particularly for students with an ASD. However, given the characteristics of the program, ST Math may likely be an effective mathematics instructional method for students with an ASD. In concert with Jordan’s (1993) recommendations for CAI for

students with ASDs, ST Math uses simple visual images to encourage spatial reasoning while minimizing the use of language and symbols. This is of utmost importance when considering interventions for students with ASDs. Language ability is tied to all other learning and behavioral constructs. By minimizing the language requirement, ST Math directly supports the visual-spatial strengths of students with ASDs. Further, ST Math provides immediate corrective feedback and masses practice, and is self-paced. Therefore, ST Math was examined to determine its potential applicability for instructing students with ASDs.

Based on this information, the following research questions were proposed:

1. Given the potentially strong match between the learner characteristics of individuals with ASDs and the features of ST Math, does the ST Math program affect mathematical achievement in students with ASDs?
2. Given the potentially strong match between the learner characteristics of individuals with ASDs and the features of ST Math, does the ST Math program affect on-task attention time in students with ASDs?
3. Is there a relationship between ST Math-related attention and achievement?
4. Does individual response to the ST Math program differ based on behavioral phenotypic expression?
5. What are the strengths and weaknesses of time series analysis as an analytic technique for intervention-based single-case research in applied educational settings?

Chapter 3: Method

Research Design

The research design for this study was a combination of single-case and comparative approaches. In 2002, the National Institutes of Health sponsored a meeting for researchers and funders of ASD research. A group of the most prominent autism researchers developed a model for validating and disseminating autism intervention information (Smith, Scahill, Dawson, Guthrie, Lord, Odom, et al., 2007). The authors recognized that no single research design can account for all of the methodological challenges in autism research. More specifically, the authors noted that conducting randomized controlled trials (the “gold standard” of research) is difficult in behavioral and educational interventions for ASDs. Thus, the authors proposed a model of four research phases that should assist in the validation of ASD interventions.

In the first stage of the model recommended by Smith et al. (2007), a new intervention is formulated and applied to selected populations to determine if the intervention warrants a large scale clinical trial. If an intervention is deemed to be possibly efficacious, the second phase consists of developing a manual and a research plan for evaluation of the intervention across multiple settings. From there, randomized clinical trials should be implemented to determine true efficacy. In the final research phase, community studies are conducted to evaluate the effectiveness and generalizability of the intervention.

The first research phase identified by Smith et al. typically relies on single-case, associational, comparative, or small quasi-experimental studies. The authors noted specifically that “one appropriate strategy to begin testing an intervention is to use single-case experimental designs” (2007, p. 356). The purpose of this initial phase is to refine the intervention and determine if the intervention has a replicable effect on a given target behavior. Further, it was noted that because ASD interventions often focus on skill building, a multiple baseline approach, as opposed to a withdrawal design, is more appropriate for these interventions. Others have echoed this stance on the importance of single-case design in intervention research, noting that “single-subject designs continue to offer strengths as initial tests of innovative treatment” (Lord, Wagner, Rogers, Szatmari, Aman, Charman, et al., 2005, p. 699).

Contemporary single-case research design developed from Skinner’s early efforts to understand behavior and learning in animals. Skinner’s behavioral experimental methodology is referred to as experimental analysis of behavior. This methodology was extended to human learning in laboratories, and ultimately, to applied settings such as psychiatric facilities and special education classrooms in the 1960s. Applied behavior analysis became the formal label for research that aided in change of clinically important behaviors in applied settings (Kazdin, 2008). Because people display unique behaviors in different settings, applied behavioral analysis functions on an individual basis, thus its reliance on single-case design.

According to Kazdin (2008), three fundamental components of single-case design work in concert to achieve experimental control. These three components are assessment,

design, and data evaluation. Repeated assessment of the construct over time allows for valid inferences about changes to be made. Assessment should occur prior to implementation, during implementation, and if desired, post-implementation. The design options of single-case research reflect this emphasis on continuous assessment. Further, stability in performance is a basic requirement of design. Baseline data and continuous monitoring is used to predict future performance based on current information given that no intervention is implemented. Subsequently, data collected during the intervention is used to predict outcome. These three components of single-case design, when implemented properly and with fidelity, work to help eliminate threats to validity and establish experimental control.

Unfortunately, insufficient resources, tools, and/or time often limit the ability to develop an adequate baseline from which to compare the effects of an intervention in applied research, particularly in the education realm. Further, assignment of individuals to groups for between- group research may be impossible or unethical. In the case of research of individuals with disabilities, insufficient numbers of participants limit the possibility for between-group designs. In instances such as these, comparative research methods must be used. Comparative research examines how attribute variables (such as an ASD diagnosis) affect an outcome (Gliner & Morgan, 2000). Comparative research, including time series design, is quite common in educational settings. Participants within a group are compared on constructs or features. Comparative research also includes elements of associational design, which examines the relationships between variables. While comparative research prevents any causal claims from being made, it is another

mechanism identified by Smith et al. as an investigation tool for potential ASD interventions.

Because the efficacy of ST Math has yet to be assessed for students with ASDs, a combination of single-case and comparative design was used in this exploratory study. A number of practical limitations required the use of a tiered methodological (and subsequent data analysis) approach. This approach allowed for comparisons within the group of participants as well as at the single-case level. Data collection took place in a highly specialized educational setting, thus participants were not assigned to intervention/treatment as usual groups. Ten students participated, which is sufficient for single-case but not for experimental studies. Progress monitoring and assessments tools that adequately assess change in academic achievement for students with ASDs have not been identified. Because of these factors, this study is not reflective of either a pure single-case multiple baseline or a comparative quasi-experimental design.

Participants

The participants were drawn from a group of 20 students diagnosed with some variation of an Autism Spectrum Disorder attending a specialized, not-for-profit autism school in metro Denver. The School's mission is to educate children with ASDs through a balanced, evidence-based, and experiential curriculum. This school was chosen for data collection because of its commitment to providing evidence-based instruction to students as well as its willingness to collaborate with the University of Denver and the MIND Research Institute.

Consent to participate was obtained from the students' parents/guardians. Assent to participate was obtained as ability dictated by the students themselves. Ten students formally agreed to participate and engaged in ST Math at least one time over the course of the 2010-2011 school year. Nine students did not participate. Students who did not participate in the research study were given the opportunity to engage in the ST Math program at teacher discretion.

Table 1 presents the demographic information of the 10 participants. All of the demographic factors have been identified as moderators in intervention efficacy (Rogers & Vismara, 2008). Further, these variables are important for individualized psycho-educational assessment and intervention development (Christ, 2008).

Table 1

Participant Demographic Information

Participant	ST Math Grade	Expected Grade	Age	Diagnosis	Comorbid Diagnosis
Participant 1	3	9	14	Autistic disorder	
Participant 2	3	8	14	Asperger syndrome	Bipolar disorder
Participant 3	1	4	10	Autistic disorder	
Participant 4	K	12	17	Autistic disorder	Fragile X syndrome
Participant 5	1	9	16	ASD	Cognitive disability
Participant 6	5	6	12	High Fxn Autism	
Participant 7	4	6	12	ASD	Bipolar disorder
Participant 8	4	7	13	Autistic disorder	
Participant 9	2	6	12	Autistic disorder	ADHD
Participant 10	K	7	15	Autistic disorder	Seizure disorder

Note. All participants were Caucasian males; ADHD = Attention Deficit/Hyperactive Disorder

Procedure/Data Collection

ST Math was implemented at The School for 10 students with an Autism Spectrum Disorder under the ST Math Pilot study (Principal Investigator, Karen Riley) during the 2010-2011 school year. Generally, quantitative analyses of the primary variables of interest (math achievement and time on task) were conducted. Subsequently, a psycho-educational profile was developed for the students based on assessments conducted for educational planning. The individual profiles were qualitatively compared to the results of the quantitative analysis of math achievement and time on task.

Based on the fidelity model from the MIND Research Institute, fidelity to the ST Math program consists of two 45 minute sessions a week. Teachers received training in September, 2010. They were advised of the recommended level of engagement (two sessions weekly) but given discretion to evaluate the extent to which their students could engage in the program. After identification of appropriate grade level through ST Math assessments, students were trained on how to access and progress through the program, following training provided by the ST Math program. For the remainder of the year, students at The School were permitted to log-in to ST Math at teacher discretion. Table 2 presents the progress of the students at The School during ST Math implementation, from October 2010 to June 2011. The primary variables of interest collected during each session for each student to form time series were time on task (time spent during a given session) and math achievement (percent of items answered correctly during a session). These variables were used to analyze individual student data.

Table 2

ST Math Descriptive Statistics

	Mean	SD
Age	13.50	2.12
Number objectives completed	3.80	4.26
Number objectives encountered	9.70	7.66
Number of log-ins	34.90	33.21
Overall progress	37%	40.7%
Overall mastery	35.5%	40%
Maximum progress	39.9%	39.8%
Maximum mastery	40.2%	40.0%

Note. $n = 10$

Pre-ST Math assessments occurred within the program when the student began a new objective. Classroom teachers ensured the completion of each assessment as needed. Post-ST Math assessments were automatically administered when an objective was completed. Pre/Post assessments are not part of the Kindergarten or 1st grade level curriculums in ST Math.

To develop individual psycho-educational profiles, file reviews were conducted. Each student at The School had an Individualized Education Plan (IEP) that contained standardized and criterion-referenced assessments. Information regarding adaptive behavior, cognitive ability, language, and any other domain-specific area was obtained through individual file reviews.

Primary Measures

Math achievement and time on task. Math achievement and time on task were the primary variables of interest in this study. Math achievement was calculated from the

percentage of items answered correctly in each session or log-in. Time on task was assessed by the length of a total session, measured in minutes. Observation points on achievement and time on task were collected every time a student logged in.

Secondary Measures

To reflect the Response to Intervention (RtI) educational reform movement, information on demographic and classification measures such as language, adaptive behavior, and autism symptomology were only obtained from students for which a priori assessment had occurred. With the current movement away from traditional test-and-place special education models, there is less emphasis on using a complete battery of domain-specific standardized assessments to diagnose and place students in special education. To reflect this change in the applied school setting, it was decided that if the data were available from prior assessments for a given student, it would be used to build the student's psycho-educational profile. Thus, not every student had information on cognitive ability, language, neuropsychological factors, or adaptive behavior. Further, different students had different measures of these psycho-educational domains. Therefore, each profile had unique domains based on different assessments.

Math achievement. Standardized academic achievement measures have long been used to identify areas of strength and weakness in individual student achievement, particularly for students in special education. The Woodcock-Johnson Tests of Achievement [WJ-ACH] (2001) is a standardized tool used to assess students' academic performance. Currently in its third revision, the WJ-III-ACH is an individually-administered assessment of academic achievement for people ages 2 to 95. The

assessment has 22 tests that can be administered and score independently or be combined to examine different curricular areas such as reading, math, and written language in the form of curricular clusters. The WJ-III-ACH tests have a standard score of 100 and a standard deviation of 15. The WJ-III-ACH math tests include Calculation, Applied Problems, Math Fluency, and Quantitative Concepts.

The WJ-III-ACH is in its third revision. The first edition was developed in 1977 and standardized on a sample of 8,800 individuals representative of the US English-speaking population, ages 2 to 90. Validity was increased by stratified random sampling across multiple geographic areas and socioeconomic status. In 2001, the WJ-III-ACH was released and norms were updated in 2007 to reflect the 2000 census changes. Split-half and test-retest reliability were evaluated. Reliability coefficients of the tests and clusters were found to range from .80 to above .90 (Woodcock, McGrew, & Mather, 2001/2007). Four students had WJ-III-ACH math data.

Cognitive ability. There is some controversy regarding the use of cognitive assessment in students with ASDs. While it has been argued that cognitive assessments should not be used as the sole determination in the educational planning of a student with autism, it is generally recognized that IQ assessment is a necessary component in research to determine comparability between participants (National Research Council, 2001). Five students had Wechsler Intelligence Scales for Children, 4th Edition (WISC-IV) or Wechsler Abbreviated Scale of Intelligence (WASI) scores which were used to measure cognitive ability. Different cognitive assessments are used because students at

The School have been administered different assessments as part of their individual educational planning.

The WISC-IV is a normative-referenced measure of cognitive abilities of children ages 6 to 16. It assesses intellectual ability through 10 core subtests and 5 supplemental subtests. Four composite scores and a Full Scale Intelligence Quotient (FSIQ) can be derived from the subtests of the WISC-IV. These composite indices are the Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), and Processing Speed Index (PSI). Each index score has a mean of 100 and a standard deviation of 15. Sixty-eight percent of children who take the test will obtain a score between 85 and 115.

The WISC-IV is the fourth revision of the Wechsler Intelligence Scale for Children. The first edition was developed by David Wechsler in 1949. The WISC-IV was standardized in 2003 on 2,200 children and adolescents representative of the US English-speaking population. Split-half and test-retest reliability were evaluated. The reliability coefficient of the composite FSIQ is .97; the reliability coefficients of the indices range from .88 to .94 (Pearson Assessments, 2003). Convergent validity was evaluated through comparison of the WISC-IV to 10 other cognitive and adaptive assessments. The correlation between the WISC-III (the previous version of the assessment) and the WISC-IV was .89.

The WASI, developed in 1999, is a brief cognitive assessment. It measures verbal and performance ability through four subtests and can be used for individuals from age 6 to age 89. It yields a Verbal IQ (VIQ), a Performance IQ (PIQ), and a Full Scale IQ

through four subtests. Similar to the WISC-IV, each quotient has a standard score of 100 and a standard deviation of 15. The WASI standardization sample of 2,245 people was representative of the US English-speaking population. The reliability coefficient for the FSIQ, based on split-half reliability measures, was .98. Convergent validity was assessed through comparison the Wechsler Adult Intelligence Scale, 3rd Edition. The correlation between the WAIS-III FSIQ and the WASI FSIQ was .92, indicating strong convergent validity. An independent review of the WASI concluded that the assessment is “relatively free from measurement error” (Garland, 2005, p. 133).

Adaptive ability. Adaptive abilities are those skills associated with everyday living. Adaptive ability can be predicted by cognitive ability. Further, higher adaptive ability has been associated with more positive outcomes in life (Liss et al., 2001). The Vineland Adaptive Behavior Scales, 2nd Ed (VABS-2) is a standardized informant-reporting tool that assesses adaptive, functional, everyday behaviors for people ages birth through 90 years. The domains include Communication, Daily Living Skills, and Socialization. An overall Adaptive Behavior Composite, Domain standard scores (average SS = 100, SD = 15) and sub-domain scaled scores (average v=15, SD = 3) are provided. Informants typically include parent or caregiver and teacher.

The VABS-2 is the second edition of the VABS originally developed in 1984. The VABS is a complete rewrite of the Vineland Social Maturity Scale, developed by Edgar Doll in 1935/1965. The VABS-2 was standardized on a sample of 3,695 English-speaking individuals from birth to 90 years of age representative of the US population. Clinical samples were included in the standardization, including people diagnosed with

autism who possessed either verbal or non-verbal communication skills. Reliability was assessed through split-half, test-retest, and interrater methods, all with alpha coefficients .80 or higher. Criterion-related validity was assessed by comparing the VABS-2 to other adaptive, cognitive, and behavioral measures.

Language, adaptive, and achievement ability. The Assessment of Basic Language and Literacy Skills—Revised (ABLLS-R) is a criterion-referenced educational assessment that tracks language, academic, self-help, and motor skills in students with developmental disabilities. The ABLLS was initially developed by Drs. Sundberg and Partington (1998) and is based on Applied Behavior Analysis theory. The major premise of the ABLLS is that language can be operationalized in increasingly discrete components, and these components can be assessed and tracked. The newest version of the ABLLS was revised in 2007.

The ABLLS is used as both a baseline assessment of abilities and areas of weakness, as well as a progress monitoring tool to inform treatment and intervention. Four major skill areas, comprised of 25 skill sets, are evaluated through observation and interview with informants by a trained administrator. The four major skill areas are Basic Learner Skills, Academic Skills, Self-Help Skills, and Motor Skills. Each skill set is ordered by developmental ability, with skills increasing in complexity and difficulty. A total of 544 specific skills can be assessed by the ABLLS.

The major weakness of criterion-referenced assessments is that they are not standardized, and thus students cannot be compared to a normative sample. The skill(s) that the student exhibits may not be reflective of what the typical population for that age

or grade exhibits. However, criterion-referenced assessments often identify more specific skills and abilities that can be directly tied to intervention and progress monitoring of said skills. Normative referenced measures, in contrast, tend to identify broad ability areas that cannot be frequently evaluated. Criterion referenced assessments are considered appropriate for educational planning because of the identification of discrete skills that can be frequently monitored. These types of assessments are designed for frequent progress monitoring whereas standardized assessments are not. The use of the ABLLS for assessing and monitoring students with ASDs is consistent with the National Research Council's recommendation that "ongoing measurement of treatment objectives and progress by documented frequently across a range of skill areas in order to determine whether a child is benefiting from a particular intervention" (2001, p. 5).

Pre/post ST Math assessments. For grades 2 through 5, each objective has a pre and post assessment within the ST Math program. Before students begin the games associated with a given objective, they answer five to ten questions to evaluate prior knowledge of the objective. Likewise, an assessment of abilities following completion of an objective is taken. Data is collected in the form of percentage of items answered correctly. These assessments are tied directly to the content presented in each objective. The assessments are not standardized or norm-referenced in any way, which is a weakness when evaluating achievement. However, the program and thus teachers, rely on these assessments to evaluate progress. Therefore, in an exploratory evaluation of the potential effectiveness of ST Math for students with ASDs, progress on ST Math specific assessments was taken into account.

Content progress and content mastery. The ST Math program calculates two variables, content progress and content mastery based on algorithms that include number of questions attempted and answered correctly, number of levels attempted and completed, and number of objectives attempted and completed. Content progress and content mastery are obtained for each objective within a grade level, as well as for the student's overall progression through ST Math. These two variables are provided in the form of a percentage, ranging from 0 to 100%. Progress and mastery are typically used to inform teachers as to the student's standing within the program, and what areas are strengths or weaknesses.

Chapter 4: Results

To address the inconsistency and irregularity of the data obtained in an applied education setting, a tiered data-analysis approach was adopted. This tiered model is reflective of data collected in applied educational settings in that data will not be available from all students across all domains or areas of interest. Research questions 1 and 2 were addressed at the group-level through correlation and paired-samples t-test. Single-case analyses were conducted through concomitant time series analysis to address research questions 3, 4, and 5.

Correlations between Variables

Chi-squared goodness of fit measures were conducted to examine relationships between categorical demographic variables. There were no significant relationships between any of the categorical demographic variables. Pearson r correlations were conducted to examine the relationships between non-time series variables. Each student had information about the number of objects completed, number of objects encountered or attempted, number of times they logged-in over the school year, total time spent in ST Math, the overall progress and mastery they made in the program, and the maximum progress and mastery obtained during the student's strongest objective.

Strong positive relationships were found between most ST Math variables, particularly the mastery and progress variables. Total time spent on ST Math was moderately related to number of objectives completed and encountered, and maximum

mastery and progress. Time was not related to number of logins. Table 3 presents the correlation information.

Table 3
Correlations between ST Math Variables

Variables	1	2	3	4	5	6	7
1. # objectives completed	-						
2. # objectives encountered	.52	-					
3. Overall progress	.54	.97**	-				
4. Overall mastery	.51	.97**	.99**	-			
5. Maximum mastery	.57	.97*	.99**	.99**	-		
6. Maximum progress	.55	.97**	.99**	.99**	.99**	-	
7. Number of logins	.33	.95**	.94**	.94**	.92**	.94**	-
8. Total time spent	.79**	.79**	.78**	.76*	.79*	.78*	.62

* $p < .05$; ** $p < .01$

Paired Samples *t*-test

A paired samples *t*-test was conducted to examine the difference between pre-quiz and post-quiz scores on ST Math objectives. This analysis was collapsed across all individuals, grade levels, and objectives, resulting in a pre-post analysis for the ST Math program as a whole. Results indicate a significant difference between pre-quiz ($M = 73.83\%$; $SD = 82.55\%$) and post-quiz objective scores ($M = 82.55\%$; $SD = 21.11\%$), $t(46) = 2.55$, $p < .05$. Overall, students exhibited higher post-quiz scores on the ST Math objectives.

Concomitant Time Series Analysis

Of 10 students who attempted at least one ST Math objective during the 2010-2011 school year, three students consistently logged in to the program as prescribed by the MIND Research Institute (twice a week). The data from these students were used to

examine whether the individual-level data collected was amenable to concomitant time series analysis. Time series analysis (TSA) is an analytic technique that accounts for the non-independent relationship between data observations over repeated measures in systems or processes expected to change over time (West & Hepworth, 1991). Used widely in econometrics and the physical sciences since the early 1900s, Kazdin and others (1978) later advocated for its use in the behavioral and psychological sciences. Given the dynamic nature of human behavior and learning, TSA is a strategy that is seemingly widely applicable to psychology and education. However, because of the emphasis on the idealized between-groups randomized experimental studies, research studies amenable to TSA have been under-used. Kazdin (1978/2008) noted that TSA is a particularly useful analytic strategy for single-case studies. Single-case design relies on repeated measurement of one case over time to identify patterns and trends in the behavior of interest. Single-case analysis has typically relied on visual analysis to determine changes in trend and level of the outcome. It has been shown that there is commonly unreliable inter-rater agreement when even trained experts use visual analysis (Kazdin, 2008). Thus, TSA offers an empirically sound alternative or addition to visual analysis in single-case research.

Time series analysis involves the analysis of variable(s) measured over time for a specific process or event, similar to regression. The repeated observations form a time series. Natural processes such as vocabulary development, or response to an intervention such as depression symptoms before and after a treatment may be assessed. The three main features of a time series are trend, seasonality/cyclicality, and serial dependence.

Time series analysis explores the extent of the presence of these features in a time series and provides methods for correcting them so that further inferential analysis can occur (Tabachnick & Fidell, 2007). Several limitations and assumptions of TSA must be addressed. A minimum of 50 observations is recommended and the observations should be measured at the same time interval. Further, the residuals must be normally distributed, the residuals must be independent (no autocorrelation), and the residuals display homogeneity of variance and zero-mean. These assumptions are examined through the pre-whitening stage (analogous to pre-analysis or data screening) in TSA.

In repeated measures data, particularly that which involves learning, trends are expected. For example, vocabulary is expected to increase over time in young children, as a normal process of development. Cycles or seasonal variations may also be present in the data, such as a spike in depression levels every seven days coinciding with a return to work. In traditional inferential analyses such as regression, it cannot be determined how much of the trend or the cyclical pattern is attributable to naturally occurring processes (random), and how much is attributable to the process of interest (deterministic). One goal of TSA is to separate the trend that occurs naturally over time from the trend that can be associated with the process of interest, and model the latter. This is referred to as making the data stationary; stationarity is an assumption of TSA (Cowpertwait & Metcalfe, 2009). Non-stationarity occurs when there are noticeable changes or drifts in the mean or variance of the data. If necessary, differencing of observations removes trends that are attributable to changes in the mean and logarithmic transformation

removes changes in variance. These processes make the time series stationary, a requirement for further model development.

The other primary assumption of TSA that must be addressed is that of autocorrelation. In autocorrelated data, there is a relationship between an observation and leading and/or lagging observations. This is a violation of the assumption of independence, an assumption that is critical in traditional inferential statistics, thereby making analyses such as F or t tests inappropriate. Autocorrelation is particularly common in single-subject data (West & Hepworth, 1991). Autocorrelation increases the standard error in ordinary least squares regression, inflating the parameter estimates and biasing the p value. The autocorrelation coefficient represents the magnitude of the serial dependence in the data and is based on lag. Lag is defined as the number of time steps between a variable; a lag can be a day, a week, a month, etc. A lag 1 autocorrelation is calculated from adjacent observations while a lag 2 autocorrelation is calculated between observations separated by two time points. The same calculations can be conducted for lead autocorrelations, but the more common practice is to calculate and interpret lag autocorrelations.

Autocorrelation may be present in both the time series as well as the residual error series (Cowpertwait & Metcalfe, 2009). To identify autocorrelation, residual error series are obtained through a typical ordinary least squares regression. The residual error series is the difference between the model fitted values and the actual data at each observation. If the time series model fits the data, the residual error series is likely a set of independent random variables, or white noise. White noise is a sequence of uncorrelated random

variables with a mean of zero. White noise is ideal in a time series because it signifies that the error terms, and thus the data, are random and have no negative statistical properties of dependence or non-stationarity. If the time series is white noise, a simple model can explain the correlations and trends in the data, without the need for further model fitting. If necessary, transforming the autocorrelations to white noise removes the dependency in the data (Pourahmadi, 2001).

There are two types of autocorrelation as identified by Box and Jenkins (1976). While some time series may exhibit both types, it is possible that a time series may display only one type (Franklin, Allison, & Gorman, 1997). The first is the autoregressive (AR) component, in which there are correlations between successive observations; earlier scores affect later scores. The second is the Moving Average (MA) component; MA explains the relationship between an observation and subsequent error terms. Box and Jenkins (1976) developed a set of procedures that examine the autocorrelations in a time series. The two models conducted as a whole are called Autoregressive Integrated Moving Average model (ARIMA).

Analytic steps. There are three stages to fitting a time series model (Box & Jenkins, 1976). The first is model identification, followed by parameter estimation and diagnostic checking. In model identification, the autocorrelation and partial autocorrelation functions are examined for patterns. The goal of model identification is to turn error into white noise. This is done through identification of the AR and MA terms in the model, either conducted separately or together through ARIMA. Based on the types of autocorrelation present in the data, a model with parameters p , q , d is developed

where $y = p + d + q$. P is the autoregressive element in the model; the value of p represents the number of autoregressive components. If $p = 0$, there is no relationship between neighboring observations. If $p = 1$, there is a relationship between observations at lag 1; if $p = k$, there is a relationship between observations at lag k . Trend is represented through the value of d ; if $d = 0$, the model has no trend and if $d = 1$, the values were differenced one time to remove the trend. Finally, q is the moving average component; if $q = 0$ there are no moving average components, if $q = 1$, there is a relationship between the current observation and the random error at lag 1. If any of the values are 0, the term is not needed in the model, as that particular model element does not exist. For example, a model identified as (1, 1, 0) indicates that there is a relationship between observations at the first lag, a trend was removed from the data through differencing at lag 1, and there are no moving average components in the time series.

In the estimation stage of time series analysis, the ARIMA (p, d, q) model is examined for model fit. The chi-square goodness of fit Q statistic evaluates model fit to determine if residuals are white noise. If the parameters fit the data adequately, diagnosis can occur. If not, a new parameter estimation must be conducted. Finally, in the diagnostic stage, the residuals are examined to determine if there are any other patterns that have not been accounted for in the model (Tabachnik & Fidell, 2007).

Concomitant time series analysis (CTSA) is a type of TSA that examines how two variables covary together over time through the calculation of cross-correlations (a basic Pearson's r) (West & Hepworth, 1991). This type of strategy is useful for examining how two variables are related over time. CTSA assumes that the variables are collected at the

same time and over equal intervals; 50 or more observations are recommended for each variable. The synchronous (lag 0) cross-correlations for the variables are calculated after removal of trends, cycles, and autocorrelations through the ARIMA process. Lagged cross-correlations may also be examined to determine if there is a relationship between a current observation of one variable and an earlier observation of the other variable. For each series, one variable acts as a lead variable and then as a lag variable; cross-correlations are calculated for both models. Cross-correlations may be computed for both the residuals as well as the time series itself upon completion of the ARIMA modeling.

To define math achievement, the percent of items correct was calculated for each session. Time on task was assessed by length of time spent in a session measured in minutes. Separate achievement and time on task ARIMA models were estimated. The models were evaluated independently and then cross-correlated. There were two time series for each participant: time spent in each log-in (hereafter referred to as “time on task” or MIN) and percentage of items answered correctly during each log-in (% correct; %COR). ARIMA modeling was conducted to the degree needed for a given time series; that is, if a time series did not display trend, no differencing was needed. Likewise, if a time series did not show autocorrelation, there was no need for ARIMA modeling. Then, cross-correlations of the time series at the synchronous model (a lag of 0) as well as at lags 1 through 7 were conducted.

Summary of CTSA steps.

1. Data screened for missingness and outliers.
2. Conduct ordinary least squares regression to obtain residuals and assess assumptions.

3. Model d value (trend): Identify stationarity through assessment of visual displays of central tendency and dispersion.
 - a. If mean is non-stationary, difference the scores
 - b. If variance is non-stationary, logarithmic transformation
4. Evaluate p (autoregression)
5. Evaluate q (moving average)
6. Estimate model parameters
7. Determine ARIMA model fit (chi-square goodness of fit Q statistic)
8. Examine residuals for any remaining patterns
9. Conduct synchronous and lagged cross-correlations between attention and percent correct for each case.

The single-case results ($n = 3$) are presented as case studies, with demographic and psycho-educational information presented first. The CTSA results are then presented for the given individual. Depending on the type of psycho-educational data available, tables are used to summarize assessment results.

Participant 1: Mark (pseudonym)

At the time of the research study, Mark, an English-speaking, Caucasian male was 14 years old. He participated in the ST Math program at the 3rd grade level; his expected grade level based on his age during the 2010-2011 school year was 9th grade. Mark received a medical diagnosis of Autistic disorder, based on findings from interviews, observation, and the Autism Diagnostic Observation System (ADOS) when he was two years old. Mark received special education services at The School under the Autism category. Mark had been prescribed two mood stabilizers and an anti-anxiety medication prior to the research study and continued to take these medications during the duration of the research study. Mark was administered the Wechsler Abbreviated Intelligence Scale (WASI) in 2010 as part of his triennial review for special education. He earned a Full

Scale Intelligence Quotient (FSIQ) of 62, a Verbal Intelligence Quotient (VIQ) of 71, and a Performance Intelligence Quotient (PIQ) of 55.

Mark's math achievement assessments include Measures of Academic Progress (MAPs) and CSAP (Colorado State Assessment Program) scores. MAPs are brief, curriculum based assessments used to monitor student progress. In the fall of 2009, Mark earned a 197, which was in the 3rd percentile for his grade. On the winter 2010 assessment, he earned a 208 (14th percentile). Mark did not complete MAPs testing in spring 2010. These scores indicate that Mark was exhibiting some growth in math. The CSAP is Colorado's measure of students' knowledge of academic standards. Scores are obtained in the areas of reading, writing, and math every year and yield Unsatisfactory, Partially Proficient, Proficient, or Advanced scores. Mark earned a score of 438 on the 2010 CSAP Mathematics section, which falls in the Unsatisfactory range. Mark did not receive standardized achievement or ABLLS assessments. Based on the information available, results indicate that math achievement was an area of struggle for Mark.

Mark's 2010 math IEP goal was "to increase his math skills" (IEP, 2010). IEP objectives included 1. Independently choosing a purchase from a store and determining how much money is needed for the purchase across 10 consecutive trials and 2. Use group problem solving strategies to solve fifth grade word problems by contributing to the achievement of an answer 9 out of 10 times. By May 2011, the end of the school year, Mark had mastered both objectives.

Mark started the ST Math program in October 2010 at the 3rd grade level. He achieved mastery of the first 3rd grade objective in November of 2010. Over the course of

the year, Mark logged in a total of 52 times, completing 15 3rd grade objectives. These objectives were: Place Value, Ordering and Comparing Whole Numbers, Expanded Notation, Addition to 10,000, Subtraction to 10,000, 2D shapes, 3D Shapes, Lines and Angles, Division, Algebraic Expressions and Equations, Fraction Concepts, Fraction and Decimal Equivalence, Fraction Addition and Subtraction, Money, and Using Data and Graphs. His highest mastery performance was on Lines and Angles and his lowest mastery performance was on Using Data and Graphs (the last objective he worked on during the school year). Seventeen imputation observations were calculated for missing data due to school holidays (one for the week of Thanksgiving, eight during Winter Break, and eight during Spring Break). Imputation for missing data was calculated by averaging the two pre and two post time series observations, per the recommendation of Tabachnick and Fidell (2007). This resulted in a total of 67 observation points for TSA.

Before analyzing the relationship between the two time series, the assumptions of TSA were addressed. Both time series were examined for trend and cycles. A positive linear trend in MIN (minutes logged in) was modeled and removed; no cycles were present in the data. Serial dependency, identified as a moving average (MA1) at Lag 1 in MIN was modeled and removed. Thus, in the original MIN time series, there was a relationship between an observation and the lagging residual, resulting in an ARIMA model of (0, 1, 1). No trends, cycles, or serial dependencies were identified in the %COR (percent correct) time series, negating the need for ARIMA modeling (0, 0 0). Table 4 shows the ARIMA modeling results.

Table 4

Participant 1 Autoregressive Integrated Moving Average (ARIMA) Model

Time series	Model Coefficients				Residual Analysis			
	Value	S.E.	<i>t</i> ratio	<i>p</i>	D.W.	<i>Q</i>	df	<i>p</i>
%COR1								
Constant	.93	.01	94.30	< .001	2.28	14.96	18	.66
MIN1								
Difference	1				1.71	19.13	17	.32
MA (1)	.84	.07	11.67	<.001				

Note. %COR = percent correct; MIN = login duration in minutes; MA(1) = Moving Average at Lag 1; S.E. = standard error; D.W. = Durbin Watson statistic; %COR1 no different than white noise, thus no ARIMA modeling necessary.

In order to examine the relationship between time on task and percent of items correct, synchronous and lagged correlations were identified. Synchronous correlations describe the relationship between MIN and %COR on the same day. Lagged correlations describe the relationship between a lead variable (MIN leading %COR and MIN lagging %COR) between one and seven days. This allows for the temporal relation between the variable to be evaluated at longer intervals. Table 5 presents the cross-correlation results. No significant correlations were identified between %COR and MIN at any lags for Mark. Thus, there was not a relationship between time on task and percentage of items answered correctly on the ST Math program.

Table 5

Participant 1 Cross-Correlations between Percent Correct and Minutes

Time series	Temporal Configuration							
	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7
%COR1lead MIN1	-.13	.04	.13	-.14	.27	.06	.01	.23
MIN1 lead % COR1	-.13	-.14	-.14	.14	.11	.09	.14	.15

* $p < .05$.

Participant 2: Benjamin (pseudonym)

Benjamin, a Caucasian, English-speaking male, was 14 years old at the time of the research study. He participated in the ST Math program at the 3rd grade level; his expected grade level based on his age during the 2010-2011 school year was 8th grade. Benjamin received a medical diagnosis of Asperger syndrome in 2009 based on information obtained from interviews, observations, and the ADOS. He was previously identified as having Bipolar disorder and ADHD. Benjamin received educational services under the category of Significantly Identifiable Emotional Disability (SIED) at The School. Throughout the duration of the research study, Benjamin took Seroquel. In 2010, as part of a comprehensive psychological evaluation, Benjamin was administered the WISC-IV. His FSIQ was in the Below Average range at 77. Benjamin earned a range of Below Average to Average composite index scores on the WISC-IV. On the WISC-IV subtests, Benjamin's highest score was on Matrix Reasoning (part of the PRI) and his lowest score was on Coding (part of the PSI). Table 6 presents a summary of Benjamin's WISC-IV scores.

Table 6

Participant 2 WISC-IV Scores

Index	Standard/Scale Score	Percentile rank	Qualitative description
Verbal Comprehension Index (VCI)	79	8	Below Average
Similarities	6		Low Average
Vocabulary	8		Average
Comprehension	5		Low
Perceptual Reasoning Index (PRI)	92	30	Average
Block Design	8		Average
Picture Concepts	7		Low Average
Matrix Reasoning	11		Average
Working Memory Index (WMI)	86	18	Average
Digit Span	6		Low Average
Letter-Number Sequencing	9		Average
Processing Speed Index (PSI)	70	2	Low
Coding	2		Very Low
Symbol Search	7		Low Average
Full Scale IQ (FSIQ)	77	6	Below Average

Benjamin was also assessed using the Vineland Adaptive Behavior Scales, 2nd Edition in 2010. Based on parent report, his Adaptive Behavior Composite was 56. He earned a Socialization score of 50, a Daily Living Skills score of 57, and a Communication score of 61, all in the Low range. Table 7 presents the results of the VABS-2 assessment.

Table 7

Participant 2 VABS-2 Scores

Index	Standard Score	v-scale score	Percentile rank
Communication	61		1
Receptive		7	1
Expressive		9	3
Written		7	1
Daily Living Skills	57		<1
Personal		8	2
Domestic		5	<1
Community		7	1
Socialization	50		<1
Interpersonal		5	<1
Play and Leisure		5	>1
Coping		7	1
Adaptive Behavior Composite (ABC)	56		<1

Note. Standard and v-scale scores = Low range

Benjamin's math IEP goal during the 2010-2011 school year was to work on 5th grade math curriculum for 90 minutes a week for six consecutive weeks. Benjamin met this goal; by the end of the school year he was working on 6th and 7th grade math curriculum every day for 30 minutes. He was administered the Calculation test of the WJ-III-ACH in 2011, which required him to compute problems without the assistance of a calculator. Benjamin earned a standard score of 71, which is in the Low range. His 2010-2011 Math CSAP score was 416, which is considered Unsatisfactory. These results indicate Benjamin's math achievement level was not commensurate with his true grade.

Benjamin worked at the 3rd grade level in ST Math during 2010-2011; his educational grade level was 8th. He logged in 84 times between October 2010 and May 2011. However, after Spring Break (last week in March 2011), Benjamin returned to objectives he had previously completed. Thus, only log-ins up to Spring Break were included in the analysis, resulting in 53 true log-ins. Benjamin completed the following

objectives at the third grade level: Place Value, Ordering and Comparing Whole Numbers, Expanded Notation, Addition to 10,000, Subtraction to 10,000. His highest mastery level was on Addition to 10,000, his lowest was on Expanded Notation. Benjamin also began ST Math by completing the first three objectives out of order. However, as the purpose of this study was to examine the time relationship, rather than adhere to progress through the program, his data was deemed usable. Eight time series observations were imputed to account for missing data: one observation in November 2010, six during Winter Break 2010-2011, and one in February 2011. This resulted in a total of 61 observation points.

Benjamin's data resulted in an ARIMA model of (0, 0, 0) for MIN, indicating no trends, cycles, or autocorrelations. Likewise, no trends or cycles were evident in the %COR series. However, an autoregressive component (AR1) at Lag 1 was modeled and removed. Thus, in the original %COR time series, there was a relationship between an observation and the subsequent observation, ARIMA (1, 0, 0). The results of the ARIMA modeling are presented in Table 8.

Table 8

Participant 2 Autoregressive Integrated Moving Average (ARIMA) Model

Time series	Model Coefficients				Residual Analysis			
	Value	S.E.	<i>t</i> ratio	<i>p</i>	D.W.	<i>Q</i>	df	<i>p</i>
%COR2								
Constant	.80	.03	27.11	< .001	1.47	9.4	18	.95
AR (1)	.34	.13	2.66	.01				
MIN2					1.89	23.66	18	.17
Constant	31.24	1.99	15.71	< .001				

Note. %COR = percent correct; MIN = login duration in minutes; AR(1) = Autoregressive component at Lag 1; S.E. = standard error; D.W. = Durbin Watson statistic; MIN2 no different than white noise, thus no ARIMA modeling necessary.

Cross-correlation of the time series showed a significant positive synchronous correlation between MIN and %COR, indicating a relationship between these two variables $r = .23, p < .05$. Further, a significant correlation was observed at Lag 1 with MIN as the lead variable, $r = .22, p < .05$. This suggests that time on task on a given day was positively related to percent of items answered correctly during the previous session for Benjamin.

Table 9

Participant 2 Cross-Correlations between Percent Correct and Minutes

Time series	Temporal Configuration							
	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7
%COR2 lead MIN2	.23*	.09	.02	-.08	-.06	-.05	.08	.10
MIN2 lead % COR2	.23*	.22*	.20	.15	-.11	-.08	.16	.05

* $p < .05$.

Participant 3: Jake (pseudonym)

Jake, a 10-year-old male, Caucasian 4th grader at The School, worked through the 1st grade curriculum in ST Math from November 2010 to March 2011. Jake has a diagnosis of Autistic disorder and received special education services under the Autism category. He was diagnosed as a toddler through a medical provider. It was known that Jake received medication; no information on specific medications was available. Jake's IEP goal was to "increase academic skills in math" (IEP, 2010). His two math objectives were: 1. Rote count and recognize numbers to 100 with no prompts (at baseline, he counted to 50) and 2. Add and subtract numbers to 20 without the use of manipulatives at an 80% success rate across three trials. By the end of the school year, Jake mastered both objectives. Jake completed the CSAP-Alternative assessment during the 2010-2011 school year, earning a Novice math score, indicating he was ready to take the standard CSAP the following year. No formal standardized assessments were available in Jake's IEP file. Throughout the year, his skills were assessed with the ABLLS. On the ABLLS, Jake mastered most areas of communication and daily living skills pertinent to his age by

April 2011. On Math skills specifically, Jake mastered through the skill of identifying what “subtract” or “take away” meant. This left seven skills Jake needed to master for his age level.

During the analysis period, Jake attempted the following objectives in ST Math: Compare Numbers to 20, Addition, Subtraction, Identifying and Classifying Shapes, Position of Shapes, Patterns, Telling Time, Numbers to 100, and Data and Graphing. He earned his highest mastery score on Comparing Numbers to 20 and his lowest mastery score on Data and Graphing. After Jake returned from Spring Break in April 2011, he returned to one specific objective (Positions of Shapes) and repeatedly worked through that objective for the remainder of the school year. Thus, all data after March 2011 were excluded; this resulted in 54 log-ins. Eight observation points were then imputed due to missingness: one in November 2010, six during Winter Break 2010-2011 and one in February 2011. This led to a total of 62 observations in the TSA.

An ARIMA model of (0, 0, 0) was fitted to the resultant MIN time series, indicating no trends, cycles or autocorrelations. A positive, linear trend was removed from the %COR series. A Moving Average component (MA1) at Lag 1 was also modeled and removed. Thus, in the original %COR time series, there was a relationship between an observation and the subsequent error, ARIMA (0, 1, 1). The results of the ARIMA modeling are presented in Table 10.

Table 10

Participant 3 Autoregressive Integrated Moving Average (ARIMA) Model

Time series	Model Coefficients				Residual Analysis			
	Value	S.E.	<i>t</i> ratio	<i>p</i> value	D.W.	<i>Q</i>	df	<i>p</i>
%COR3								
Difference	1				2.02	23.98	18	.16
MA (1)	.86	.07	11.85	< .001				
MIN3								
Constant	2.56	.10	24.54	< .001	1.75	23.38	18	.18

Note. %COR = percent correct; MIN = login duration in minutes; S.E. = standard error; MA(1) = Moving Average component at Lag 1; D.W. = Durbin Watson statistic; MIN3 no different than white noise, thus no ARIMA modeling necessary.

Cross-correlation of the time series showed a significant positive synchronous correlation between MIN and %COR, indicating a relationship between these two variables $r = .23, p < .05$. Further, a significant correlation was observed at Lag 1 with MIN as the lead variable, $r = .22, p < .05$. This suggests that time on task on a given day was positively related to percent of items answered correctly in the previous session for Jake.

Table 11

Participant 3 Cross-Correlations Between Percent Correct and Minutes Spent

Time series	Temporal Configuration							
	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6	Lag 7
%COR3 lead MIN3	.25*	-.12	-.20	.02	-.17	-.08	.04	-.12
MIN3 lead % COR3	.25*	.06	.06	.00	-.21	-.02	.07	-.04

* $p < .05$.

Overall, results indicate increases scores between pre and post quizzes across all grades and objectives. Further, relationships between time spent on ST Math and percentage of items answered correctly were observed in two out of three students who had sufficient time series data.

Chapter 5: Discussion

Results from the tiered data analysis indicate the ST Math program has a positive effect on the math achievement of students with ASDs. Comparative analysis indicates higher post objective scores for all students. Students with particular behavioral phenotypes tended to progress through the program more so than other students. There was a relationship between time spent in the program and percentage of items answered correctly for two out of three students with significant program progression. Finally, time series analysis was shown to be a useful statistical analysis approach for single-case repeated measures educational data. Further investigation of ST Math as intervention for students with ADSs is warranted.

ST Math Effect on Achievement and Attention

The first two research questions considered the possible effect of ST Math on math achievement and time on task for students with ASDs. Research question 1 was: “Given the potentially strong match between the learner characteristics of individuals with ASDs and the features of ST Math, does the ST Math program affect mathematical achievement in students with ASDs?” Research question 2 was: “Given the potentially strong match between the learner characteristics of individuals with ASDs and the features of ST Math, does the ST Math program affect on-task attention time in students with ASDs?”

Analysis of pre-post objective quiz scores on the ST Math program indicated that students with ASDs exhibited higher post-quiz scores across all objectives and grades attempted. A number of factors may have contributed to this change, such as general maturation or increasing familiarity with the specific task or the program as a whole. However, these results are consistent with prior quasi and controlled experimental studies conducted by the MIND Research Institute indicating that students who engaged in ST Math showed stronger performance on the post-objective ST Math assessments (Richardson et al., 2010). Overall, the students at The School showed a 37.5% mastery level for the year, indicating that the average amount of grade level content mastered was 37.5%. Movement to the next grade level occurs when 95% or higher mastery is reached. The three students who participated the most frequently in the ST Math program had a higher overall mastery level compared to the remaining seven students. Further, the three students who participated the most frequently in ST Math all met their IEP goals for the school year in which the program was implemented. This indicates that ST Math did affect math achievement, likely in a positive manner.

Five other peer-reviewed studies have examined math interventions for students with ASDs using a single case design. These studies focused on direct instruction of a discrete skill, such as counting-on (Cihak & Grim, 2008) or touch-point math (Cihak & Foust, 2008), rather than on improving overall math achievement. In each of these studies, the participant(s) showed increased discrete skill ability. Thus, the results of this study are consistent with the limited prior research on math intervention success for students with ADS. The results contribute to this research in a different way. ST Math

does not rely on direct or class-wide teacher instruction, thus potentially providing teachers with more flexibility and time in direct instruction and overall lesson planning.

The data are less clear regarding the effect ST Math may have had on time on task. The ten students spent a wide range of overall time on the program. Total time on task was positively related to the number of objectives students encountered and completed, as well as overall mastery and overall progress. For two of the three students who logged in frequently, time on task did not increase over the year. However, a positive trend in time on task was observed for one student, indicating that he increasingly spent more time on ST Math as the year progressed. Benjamin's IEP goal was specifically related to increasing academic engaged time spent in math (time spent on ST Math counted). At the start of the school year, the student spent about 30 total minutes a week engaged in math. By the end of the year, he was spending 30 minutes a day, every day, engaged in math instruction. While a general noticeable improvement in math academic engaged time was not observed in ST Math, individual students showed increases in time spent on ST Math.

Applicability of CTSA to Educational Data

Despite the frequent use of single-case design in educational research, time series analysis has rarely been used to empirically evaluate the results. Thus, two of the research questions addressed the applicability of CTSA to time series data derived from an applied educational setting. Research question 3 was: "Is there a relationship between ST Math-related attention and achievement?" Research question 5 was: "What are the strengths

and weaknesses of time series analysis as an analytic technique for intervention-based single-case research in applied educational settings?”

Research questions 3 and 5 were addressed through concomitant time series analysis. CTSA conducted on individuals’ time series data showed a relationship between time on task during a session of the ST Math program and percentage of items answered correctly during that same session for two of the three students. There was no relationship between time on task and math achievement for Participant 1, Mark. Mark’s original time series data did indicate a positive linear trend in minutes spent in a session and an autocorrelation between an observation and the subsequent error term. Thus, as the school year progressed, Mark spent increasing amounts of time engaging in ST Math. Minutes in a session on a given day were positively related to minutes spent in a previous session. Once this autocorrelation was removed, the relationship disappeared.

In Benjamin’s data (Participant 2), there was a positive, weak relationship between time spent in a session and percentage of items answered correctly. Benjamin answered a higher percentage of questions correctly the more time he spent in a session. There was also a significant correlation at Lag 1 when MIN led %COR, indicating a relationship between minutes spent in session on a given day and the previous session’s percentage of items answered correctly. This could be attributed to Benjamin doing well on a previous session, causing an increased desire or motivation to spend more time on the program in the next session. Or Benjamin may have been cognizant of, supported by teachers, and working towards his IEP goal of increasing total time spent engaged in math learning. Participant 3, Jake, also showed a weak, positive relationship between

time spent in a session and percentage of items answered correctly in that session. Further, Jake's original %COR time series showed a positive linear trend and a relationship between an observation and the preceding session's error—a Moving Average component—both of which were modeled and removed.

Two out of the three students showed a higher percentage of items answered correctly the longer they spent in the program. These findings support the belief that there is a positive relationship between academic engaged time and increased knowledge acquisition. It also suggests that engaging in ST Math helped increase knowledge about discrete math skills for some students with ASDs. This may be related to the attentional profiles identified in students with ASDs. Specifically, students with Autistic disorder have been found to have strengths in sustained attention, almost to a fault where they cannot orient away from objects of interest (Goldstein et al., 2001). It is possible that the ST Math program provided visually-stimulating information that captured and sustained the attention of certain students over others. Thus, spending more time working in the program in order to master the content should be encouraged for students with ASDs. ST Math should be further investigated as an intervention for students with ASDs.

Benefits of CTSA. The concerns usually associated with repeated observation measurements were seen in the time series data. Naturally occurring trends were identified in two of the time series. Several of the time series contained autocorrelations; one Autoregressive component and two Moving Average components were identified. Without the pre-whitening stage that is critical to proper TSA, the deterministic effects of the trends and autocorrelations would have skewed any further inferential analyses (such

as correlations or regressions). This in turn, would have increased the likelihood of committing a Type II error (Tabachnik & Fidell, 2007). Had these data been analyzed without accounting for the trends and serial dependencies, the results would have been inaccurate. Instead, accounting for these mechanisms resulted in the appropriate identification of relationships of interest. Thus, TSA can be considered a useful statistical analysis for repeated observation educational data.

Single-case design is built on the premise of repeated collection of observations over time. Statistical analysis is not commonly used in single-case designs; instead conclusions are made based on visual inspection of the data (Kazdin, 2008). If enough observations are collected over equally spaced intervals, TSA can be a useful addition to or substitute for visual inspection. This will provide more sound description and interpretation of the results. Further, once trends, cycles, and autocorrelations are accounted for, higher level inferential analyses, such as interrupted TSA or regression can be conducted. Single-case applied research is common in education but concerns about the validity of results are abundant. This study supports the claim made by Kazdin that education is a field that would benefit from the use of TSA in analyzing single-case data.

Overall, after accounting for trends, cycles, and serial dependencies in these time series, weak relationships were found between time on task and math achievement in two students with ASDs. This is the first study of its kind to address single-case math achievement data for students with autism. This research adds to the body of evidence already available about the effectiveness of ST Math as a math intervention program. It also examines a potential math intervention that can be used specifically with students

with ASDs. Finally, it offers an example of an alternative method to data analysis of single case data. This study shows that continuous progress monitoring educational data can be analyzed in a statistically sound manner.

ST Math and Behavioral Phenotypes

As expressed by Kazdin (2008) and Hodapp and Dykens (1997), the identification of behavioral phenotypes can be assisted through response to intervention. A major goal of this research study was to determine if students with different behavioral phenotypes responded differently to the ST Math program. Research question 4 was: “Does individual response to the ST Math program differ based on behavioral phenotypic expression?”

Similarities in behavioral phenotypes were identified among the three participants who consistently engaged in ST Math. The students were in late childhood or early adolescence (ages 14, 14, and 10) and showed a wide gap between their expected grade level based on age and their ST Math grade level (differences of 6, 5, and 3 grade levels). The students had medical diagnoses of either Autistic disorder ($n = 2$) or Asperger syndrome, and all three were taking medication for symptom management.

The two cognitive profiles available indicated low global cognitive ability. The common $PIQ > VIQ$ difference in Autistic disorder was not observed in Participant 1. Instead, Mark’s verbal abilities were stronger than his performance abilities. This reflects Dyck et al.’s claim that analysis of group means may support the $PIQ > VIQ$ difference observed in Autistic disorder, but that individual differences must be taken into account when evaluating an individual’s abilities and needs (2007). The student with Asperger

syndrome (Participant 2, Benjamin), had stronger performance abilities than verbal abilities, which is similar to recent research indicating that individuals with Asperger syndrome may show mixed cognitive profiles (Barnhill et al., 2000). Math achievement ability, as indicated by WJ-III-ACH, CSAP, and ABLLS scores, as well as IEP goals, was identified as well below grade level for each student. IEP goals ranged from functional money ability, to engaged time on task during math, to basic computation skills. Each of the three students mastered their IEP goals by the end of the school year. Of particular note is that measures which assessed communication and language indicated that all three students possessed verbal language abilities. The student with Asperger syndrome had average language capabilities whereas the students with Autistic disorder had low or low average language skills.

These profiles can be compared to the seven students who either did not or could not complete a significant portion of the ST Math program. Students who did not progress in the program were generally in higher grades (6 through 12), but worked in ST Math lower grades (K through 2). This indicates a major discrepancy between actual grade and achievement ability, particularly when compared to the three students who made progress. The majority of these students had an Autistic disorder diagnosis and had comorbid diagnoses, including fragile X syndrome, seizure disorder, and bipolar disorder. Available cognitive scores from students who did not progress through the program were in the moderate range of intellectual disability (50 or lower).

One sixth grade student (Participant 6) with a diagnosis of High Functioning Autism, worked through one objective at the 5th grade level, obtaining immediate

mastery. He did not continue further in the program. This student's WISC-IV scores were: FSIQ = 113; VCI = 110; PRI = 121; WMI = 116; PSI = 85. His math academic achievement as measured by the WJ-III-ACH Calculation subtest was in the average range (SS=105). It is likely that the 5th grade curriculum of the ST Math program was too easy for this student and thus was abandoned after one objective. This is an example of a student for whom the program did not work because the curriculum was too easy.

An alternate profile is offered as an example of a student who made the least progression in the ST Math program. Participant 4 was a 17 year old Caucasian male who attempted the Kindergarten curriculum of ST Math. He had a diagnosis of Autistic disorder and fragile X syndrome. This student completed the first objective of the Kindergarten curriculum and did not move further in the program. The student did not complete the CSAP-A. His cognitive scores indicate moderate intellectual disability, with a FSIQ of 48. Adaptive measures reflect significant concerns in adaptive ability, with all scores in < .1 percentile. This student is clearly impacted by his disabilities, which may indicate that the ST Math program was not sufficient to meet his needs. Alternatively, the student, being much older, may have felt that the pictures and images were too immature. There are a multitude of reasons why this student did not make progress in ST Math.

Based on these behavioral profiles, it appears that ST Math may be more useful for older students with low or low average IQs, communication, and academic achievement abilities. Students who are more severely impacted by the disability, including having IQs or adaptive abilities in the moderate or profound range, or very low communication skills may need to begin ST Math curricula at the Kindergarten level or

may not benefit from the program. Middle and high school students with average cognitive and achievement abilities may not benefit because they possess higher abilities than the program addresses.

The identification of behavioral phenotypes allowed for an in-depth exploration of who the ST Math program benefitted versus who it did not. Gathering information about cognition, adaptive abilities, academic achievement, and language led to the development of detailed phenotypes. Comparing progress and outcomes in ST Math with the subsequent behavioral phenotypes identified several similarities and differences. These details are critical for examining “what works for who and why” (Kazdin, 2008) in the search for both interventions that ameliorate behavioral, psychological, and academic challenges in individuals with ASDs as well genetic or neurological causes of ASDs.

Implications for Practice

This study encountered a number of experiences and challenges that are often associated with translational research, applied research, and research with students with disabilities. The very definition of translational research emphasizes the importance of cross-discipline collaboration (Cicchetti & Toth, 2006). In this research project, collaboration across several institutes was necessary: the MIND Research Institute, University of Denver, and a private not-for-profit school. Likewise numerous disciplines were involved including psychology, education, neuroscience, software engineering, and business. Various professionals collaborated to develop the ST Math software (neuroscientists, software developers and engineers, data analysts) and subsequently launch the research study (professors, graduate students, business professionals, teachers,

school administrators, interventionists, and paraprofessionals). Each professional had a unique role in contributing to the success of the study.

The National Academy of Sciences, as cited in Cicchetti & Toth, 2006, describes translational research in terms of interdisciplinary collaboration:

a cooperative effort by a team of investigators, each of whom is an expert in the utilization of different methods and concepts and who have united in an organized manner to address a challenging problem (p. 620).

In order for translational research to be successful, all parties must adhere to the notions of “united” and “organized.” The common “problem” that all parties involved in this study were intent on changing was math achievement. However, this goal differed for the institutes and the professionals. For example, the goal of the MIND Research Institute was to develop, market, and sell a math program for all students. The University of Denver professionals’ goal was to examine the program specifically with students with ASDs, whereas the professionals at The School sought to increase their individual students’ level of math achievement. This difference in goals was a challenge; the lack of uniformity of the goal led to issues with communication, knowledge, and seeming interest in the project.

Ecological validity in applied settings. Because this study took place in an applied educational setting, the standard validity controls could not be put into place to ensure the research study followed a strict protocol. In a research laboratory, parameters are developed to ensure that specifications of the experiment or intervention are followed exactly as planned. This same concession cannot be made in field settings, particularly those of an educational nature. Further, this is especially true when working with students

with disabilities; adaptations must be made based on the needs of the child on an extremely frequent basis. It is important that there be flexibility in research protocols in educational settings because educational settings are such dynamic, fluid systems. In these settings, a balance must be struck between adherence to the research protocol and adaptability of the protocol to the environment. Recognizing the extremely dynamic nature of The School and the study participants, very few research parameters were put into place regarding delivery of ST Math. While all staff were trained on the program and encouraged to have their students log in twice a week for 45 minutes, teachers were essentially permitted to use their discretion in implementation of ST Math. The decision to be flexible regarding the research protocol increased the ecological validity of the results.

One method that helps when conducting research or implementing interventions in applied settings is empowering the implementors of the program so they take ownership and pride in the project. In this particular study, The School director made the decision to participate and notified teachers of the decision. Further, teachers were required to come in on a day off to train in ST Math. Both of these parameters may have led to teacher dissatisfaction, and subsequent lower levels of student participation. Empowerment of teachers to participate in the research study could have been used to help increase participation by the students. Empowerment of teachers through teacher buy-in, consultation in the development of the intervention program, and other skill-building techniques allows teachers to contribute to the research. In applied educational research, teachers and other school staff must be willing to participate and empowerment

helps them gain skills in research. If the interventionists or field researchers fail to implement the research parameters with fidelity, true conclusions about efficacy or effectiveness cannot be obtained.

On a similar note, there must be a balance between the level of support provided by researchers to the educational staff. School staff need enough support in order to conduct the intervention. Ultimately, the staff need to be able to implement the intervention with fidelity on their own with no support. If too much support is provided early on, school staff may come to rely on and expect the support. If too little is provided, the research protocol will not be followed as directed. In this particular study, a number of students did not complete the ST Math program as directed by the research protocol (twice a week). Reasons for this are unclear; part of the purpose of the study was to determine which students responded better to the program than others. However, at this point, it is unknown if the lack of data stems from teachers' skill level or opinion of the program, or if it was because the students could not or did not want to complete the program.

Data acquisition in this study was a challenge. Data were acquired from two sources, including the MIND Research Institute and The School. On several occasions, data that was expected to be available was either partially available, or not available. At The School, each student had slightly different types and amounts of educational data, based on special education eligibility, teacher assessment preferences and qualifications, and services received. Researchers relied on these outside sources for data, rather than conducting a laboratory experiment or going to The School to collect the data without

assistance from school staff. Although this was a significant challenge in the study, the resultant data proved more true to the nature of educational settings. The results are more likely to be ecologically valid because they were conducted in the school. Further, the data obtained reflect the type of data likely to be obtained from an educational setting—imperfect and incomplete.

Ethics in applied research. Applied educational research poses particular ethical dilemmas. As noted, this study is the first of its kind to evaluate ST Math for students with ASDs. It relied on a very small sample size, and data analysis had to conform to the type of data collected by the ST Math program and The School. Quasi- and true experimental studies were not feasible or even ideal at this early stage of research. However, researchers must maintain ethical commitments to any potential benefactor of the intervention regardless if they were research participants. Beneficence is an ethical principle in all research, but seems extraordinarily important if the research has the power to transform the life of a person with a profound disability or illness. Based on the research design and the statistical analysis, it is not possible at this point to determine the true impact ST Math has for students with ASDs. There is danger in stating that an intervention should be further examined for efficacy if the intervention truly does not work. Ethical questions can be raised if a recommendation for dissemination of ST Math as an intervention for students with ASDs is made, and the program actually does not have a strong impact. Likewise, if ST Math has a more significant positive effect on math achievement for students with ASDs than what was demonstrated in this study, we are potentially limiting the math achievement growth of these students by not recommending

it as a widespread intervention. ST Math has the potential to provide math curriculum access to students with ASDs in a novel way, and it is important to keep in mind the ethical principal of beneficence when considering future research.

Contributions

This study was the first of its kind to assess the relationship between ST Math and the phenotypic profiles of students with ASDs. Only five other peer-reviewed studies were identified that examined a math intervention specifically for students with ASDs. Each of these used direct instruction on one discrete skill. This study adds to that body of literature by considering how a computerized intervention affects math achievement. This study also contributes to the literature on statistical analysis in single-case design. Time series analysis has been used sparingly in applied education and psychological research. This study shows that TSA can be useful in describing and modeling individual-level time-based data, particularly educational data.

Success in ST Math was observed in individuals with common behavioral phenotypes. When considering how this study contributes to the translational research model, the next step should seek to answer: what was similar *and* different about the three students who progressed through ST Math compared to the seven students who did not. Distinctions in behavioral phenotypes of the students are evident. Applying these findings of the differences in behavioral phenotypes and response to an intervention to basic science research would be reflective of the bidirectional nature of translational research. The question of interest then becomes: what are the genetic or molecular underpinnings of these phenotypic characteristics? This study provides one step towards

cross-collaborative trans-disciplinary research in the fields of education and Autism Spectrum Disorders.

Limitations

The mixed method use of single-case design and comparative design, with a sample size of 10, limits the generalizability of the study as a whole. Data was only collected from students at The School. This may have led to biased results, as the students who attend The School may have more significant learning needs than students who attend traditional public schools. Due to the profound lack of research on mathematical academic achievement in students with ASDs, there are no known standardized math measures that can be used to accurately and repeatedly analyze baseline or post-intervention abilities. Thus, traditional single-case designs that use comparisons between baseline (pre-intervention) and treatment (such as ABAB designs) are not easily implemented when examining changes in math achievement for students with ASDs. Maturation or history, threats to internal validity, were not controlled through design, but rather assessed through statistical analysis. Because most norm-referenced standardized assessments cannot be administered more than one time a year, there is no way to assess change over time on domain specific areas such as adaptive behavior.

Future Research

Based on Smith et al.'s (2007) recommendation on the process of identifying interventions for students with ASDs, further single case or simple comparative designs should be conducted. In order to continue the applicability of this research to translational models, further development of the phenotypic profiles of students with ASDs who

succeed versus those who do not in ST Math should occur. This will allow continued investigation into the processes of the intervention, as recommended by Kazdin (2008). ST Math should subsequently be assessed as part of a quasi-experimental or randomly controlled study to determine true efficacy.

Further expansion of research in the area of behavioral phenotypes can be accomplished by investigating the effectiveness of ST Math for students with disorders that have a known genetic etiology. This is in line with De Vries and Oliver's (2009) recommendation that translational research and behavioral phenotypes focus primarily on disorders with known genetic etiologies in order to transfer that knowledge to other disorders. Students with fragile X syndrome or Down syndrome may also benefit from a pictorial based math intervention program. By identifying how these students respond to the intervention, more specific delineations of behavioral profiles can be developed and then applied to students with ASDs.

The students at The School may have more significant learning needs than students with ASDs served in public school settings. In order to generalize results to a broader spectrum of students with ASDs, ST Math should be examined with students in Autism center programs in public schools, and with students with ASDs who served within resource special education and in general education. This information will assist in identifying the generalizability and feasibility of using ST Math with students with a wide range of abilities.

The most basic level of time series analysis (CTSA) was conducted in this study. Thus, further research should examine the use of Interrupted Time Series Analysis in a

study examining ST Math and ASDs. ITSA is a form of time series analysis in which the impact of an intervention is modeled and examined. Replication of the use of time series with educational repeated measures data should also occur, given that this is one of few studies to use TSA with behavioral and psychological data.

ST Math should be considered for further exploration, given the potential for success observed in this study. It should be examined in concert with increasingly specific ASD behavioral phenotype delineations, and with students with genetic neurobehavioral disorders. Between-group experimental research will also help identify if ST Math causes increased academic achievement in students with ASDs and if the achievement is different from that observed in typically developing children.

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