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Lighting Neural Maps: Using a Neuroscience Lens to Examine Quantitative Performance from Urban Districts

Hengameh (Heny) M. Taraz
htaraz@lesley.edu

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Using a Neuroscience Lens to Examine Quantitative Performance from Urban Districts

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Hengameh (Heny) M. Taraz

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Approvals
In the judgement of the following signatories, this Dissertation meets the academic standards that have been established for the Doctor of Philosophy degree.

Prof. Susan Rauchwerk ______________________________ _______________
Doctoral Committee Chair Date

Prof. David Morimoto ______________________________ _______________
Doctoral Committee Member Date

Prof. Carina Pamela Curto ______________________________ _______________
Doctoral Committee Member Date

Dr. Jeffrey Perrin ______________________________ _______________
Director, Individually Designed Specialization Date

Dr. Valerie Shinas ______________________________ _______________
Chair, Ph.D. Educational Studies Date

Dr. Dana Fusco ______________________________ _______________
Dean, Graduate School of Education Date

Dedication Page

Education is a tool to find the best in you. — Taraz

For my lovely sons and all the wonderful students who light up my world with their curiosity and love for learning. I hope you find the best in you, be grateful for what you have, and give back to future generations.

Acknowledgements Page

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I am truly blessed to be surrounded by an abundance of kindness, grace, warmth, and love interwoven into my perception of life.

Abstract

What is the link between neuroscience and education? Can one measure the phenomenon of learning and make predictions by charting student performance? How does the knowledge of neuroscience inform educators to objectively and effectively meet the unique needs of all learners and address discrepancies in subsets of student population? Questions like these led the way to examining quantitative summative performance assessment data obtained from two large and diverse urban school districts in the Commonwealth of Massachusetts. This interdisciplinary study is an empirical mixed methods inquiry that includes extensive quantitative analysis of existing public school data which is further analyzed using a qualitative neuroscience lens developed by synthesizing recent neuroscience research on topics such as cognition, neural synchronization, childhood anxiety, and understanding high IQ students through an integrative literature review. Neuroscience is the radiant light crucial for informing educational policies and practices that actively provide and improve training for teachers and staff, develop meaningful pedagogy and measures for assessing students, and build effective bridges between home and school by educating all stakeholders. In this empirical examination, emerging themes of longitudinal growth in performance and performance score variance in terms of gender and economic status highlighted connections that are explained in the language of neuroscience as applied to the field of education while identifying and defining neuromyths. Ultimately, this analysis revealed findings such as the predictability power of performance assessment scores beyond their current utilization and identified performance discrepancies in the two subsets of gender and economically disadvantaged students. This research connects the two fields of neuroscience and education and provides a comprehensive framework, suggesting newly informed and neuromyth-free methods in teaching and learning that are commensurate with students' natural ways of learning. This is an invitation to engage in an innovative neuroscience-informed design and structure that provides educators and parents with competent preventive and intervention strategies towards creating healthy ecosystems aligned with the most recent research in neurobiology, neuropsychology, and cognitive neuroscience.

Keywords: neuroscience, integrative review, quantitative analysis, student performance, neuromyths

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CHAPTER 1: INTRODUCTION

Only True artists are attracted to science

— Cajal

Dawn chorus is a marvelous chant of the songbirds' rhapsody, awakening the Earth moments before daybreak in July. The waves of the alluring sounds, the splendid dance of the honeybees, and the solitude of the summer months afford me time to ponder, reflect, and create. But when I walk in the woods and through the town, it is the laughter and free spirit of children that permeates my brain. I wonder about their learning, and how it is incumbent upon us, neuroscientists and educators, to explore and facilitate methods in teaching and learning that is commensurate with their nature. In late August, the clicking melody of cicadas and the soft breeze salute students on the first day of school. From a distance, lines of school buses pull up one at a time with small spaces between them, like the white agate beads of my grandmother's rosary spaced securely along a string. They remind me of Cajal's discovery of synapses, the microscopic communication points between neurons, little gaps that allow for neural communication, the language of brain cells (Jasanoff, 2018), a humming ensemble of thoughts that oscillate and never sleep.

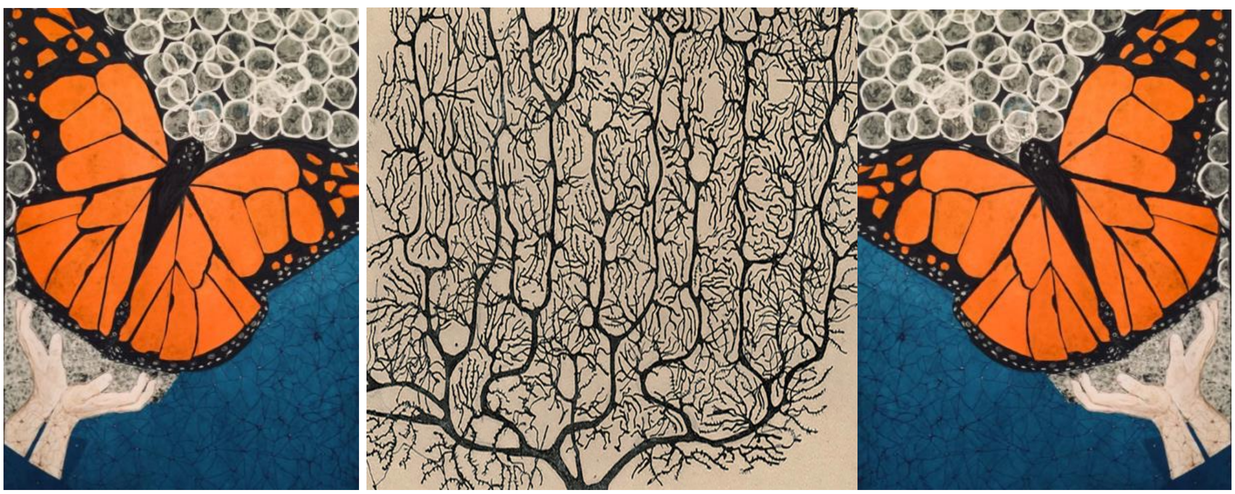
Santiago Ramón y Cajal (1852-1934), the "father of modern neuroscience," (Ehrlich, 2022; The Nobel Prize, n.d.; Rapport, 2005) was both an artist and a scientist, fiercely motivated to find the truth about the brain and its processes. For decades his dark eyes were peering through the old microscope, his laboring hands moving back and forth gently positioning the slides on the stage and when the light beamed through, he drew meticulously detailed sketches of neurons. Cajal's truth was hidden in the structure of the neurons, and the function of the neurons he deduced with respect to their architecture, which he called “the religion of the cell” (Ehrlich, 2022, p. 278).

I posit when artists create, they must examine their objects with precision, considering their form, shape, reflection of light, and the relationship of the objects to their background and other encompassing elements. When scientists set out to discover, they begin with inquiry, formulate hypotheses, examine objectively and think critically using tools that illuminate the way for their observations. They are directed by scientific inquiry and driven by their own intuition. In my opinion, “True” artists and scientists have one fundamental commonality, and that is their search for the truth by their own contemplative discretion, using the light to guide them in their paths. In order to reach the truth, one must question, reexamine, and reevaluate to identify myths, both current and dated, often quite hard to surrender and sometimes painful to peel.

I genuinely connect with the work of Cajal, neuroanatomist, educator, author, artist, and Nobel laureate in physiology and medicine, 1906 (The Nobel Prize, n.d.). We share many views; the use of metaphors and allegories in writing, creating stories, investigating, believing in one’s craft, exhibiting veracity, and being true to oneself in light of the work. Cajal (as cited in Ehrlich, 2022) treated each neuron as a “distinct individual” (p. 270). I too, strive to treat my students as “distinct individuals.” He consistently saw beauty in the small wonders of nature, exhibiting “clear affection” and respect for the “hardworking creatures,” asking what he can learn from them (Cajal, as cited in Ehrlich, 2022, p. 270). In my long walks with a magnifying glass in my pocket, I frequently rely on nature for grains of wisdom, and respectfully watch my students to see what I can learn from them while asking how I can facilitate their learning naturally. Cajal pondered the behavior of neurons and I contemplate the behavior of children, and we both do not believe the word failure exists. For Cajal and me “positivism is the law of the land,” (Cajal, as cited in Ehrlich, 2022, p.170). Cajal studied neurons with empathy and adoration, “the mysterious butterflies of the soul whose beating of wings may one day reveal to us the secrets of the mind” (Cajal, as cited in Ehrlich, 2022, p. 207). And I, with every effort, aspire to discover the light to help me find the best ways to further learning in my students, whose well-being, laughter, and exuberance awaken “the butterflies of my soul” (see Figure 1) and usher me back to school.

Figure 1

Mysterious Butterflies of the Soul



Note. Center panel, Santiago Ramón y Cajal’s illustration of Purkinje corpuscle of the human cerebellum, from *The Beautiful Brain: The Drawings of Santiago Ramón y Cajal*, by L. Swanson, 2017, Abrams Books. Right and left panels, Hengameh Taraz’s collage illustrating the process of learning, titled *Designed to Soar: A Cognitive Journey Through Connections*, Copyright 2016.

Statement of the Problem

The primary goal addressed in this study is to examine connections and disparities that are evident from summative performance assessments in both abilities-based and standards-based data. In doing so, this study aims to apply knowledge of neuroscience to the findings in order to understand how connections can be fostered and disparities can be prevented, reduced or even mitigated. With this focus, two major causes of the stated problem are considered. Firstly, the rapid rise in technology, higher work demands, changes in family structure, declining value systems such as reduced family time, absence and distraction of parents and caregivers, as well as the aftermath of a pandemic amongst other ongoing societal concerns, contribute to anxious feelings and observed disparities in schools. This negative ecosystem is leading to profound consequences such as unhealthy competition, physical and mental health concerns, lack of personal fulfillment, individuality, motivation, willpower, compassion, and deficits in creativity (Anderson, 2014; Limone & Toto, 2021; OECD, 2011; Popenoe, 1996; Small et al., 2020; United States Census Bureau, 2016-2022).

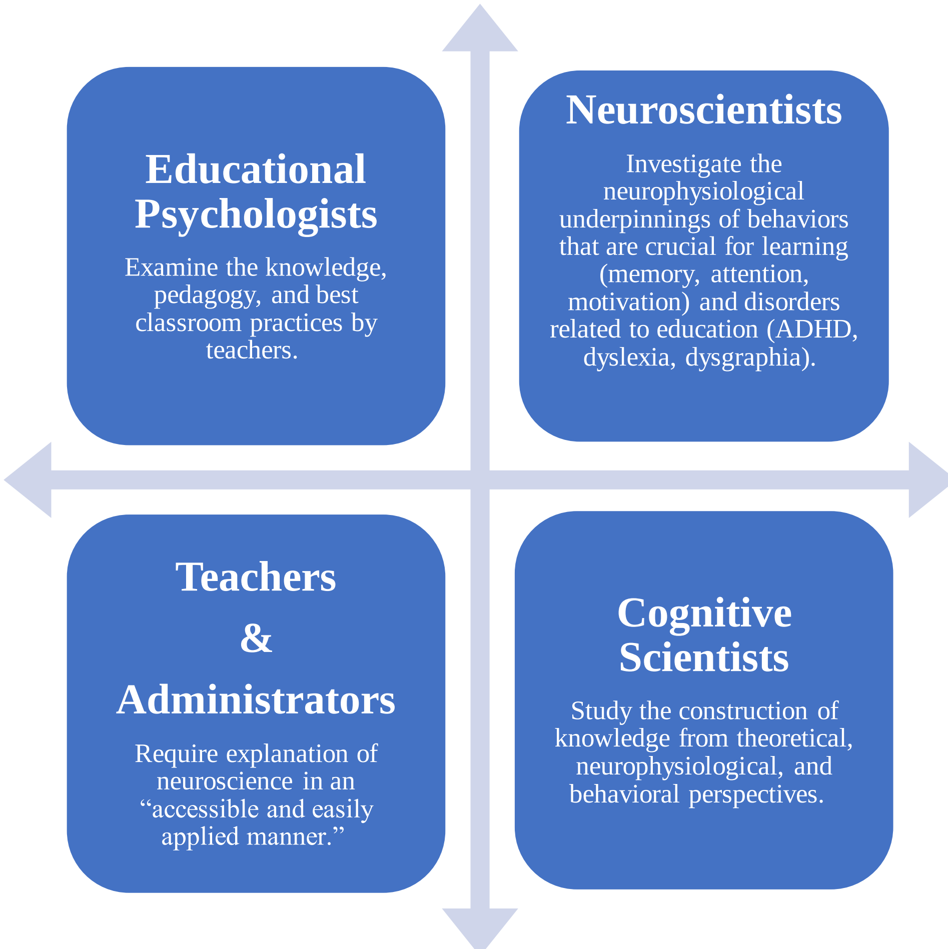
This study aims to inform how we can support children's well-being and properly educate and help them grow into healthy, caring, and responsible adults. Fostering healthy child development begins before children enter school. In a comparative study, Suskind and Denworth (2022) found that children in the United States are "falling behind" as compared to other nations. This examination points to interventions needed in early childhood to prepare students for school. According to the Organization of Economic Cooperation and Development, (OECD; as cited in Suskind & Denworth, 2022), a research study revealed that 50% of American children performed lower in literacy and numeracy scores, demonstrated lower skills in managing self-regulation, and illustrated lower "prosocial behaviors" such as cooperative skills and acts of kindness, as compared to children in other nations. The authors contended that "care and cognition" (see Appendix D) are connected, and that providing children nurturing relationships with parents and caregivers and protection from "toxic stress" is critical to healthy child development. Brain imaging provides evidence to this claim by illustrating higher levels of activation and connection in brain areas relevant to language and cognitive development. Suskind and Denworth stated societal changes are needed for improvement. They suggested paid parent leave and quality childcare programs across the country and providing knowledge of neuroscience in brain development as part of a public discussion to remedy the growing issues.

Secondly, it will serve us well to lean more on the work of neuroscience researchers whose investigations and interests are commensurate with healthy child development and natural growth. There is a lack of a common language or "usable knowledge" (Chang et al., 2021; Clement & Lovat, 2015) of neuroscience that can be effectively practiced by teachers in their classrooms (Chang et al., 2021; Clement & Lovat, 2015; Jolles & Jolles 2021; Wilcox et al., 2021). Our educational system was mainly constructed by educational psychologists and policymakers who focused on transmitting information to students and teaching problem-solving skills (Berlinger, 1993; Slavin, 2003). While teacher preservice and professional development require child psychology courses, they are missing proper neuroscience literacy and training (Coch & Daniel, 2020; Grospietsch & Mayer, 2019). Neuroscience research can have a profound influence on teacher training, pedagogical practices, curriculum and instruction, and in interpreting behaviors. Knowledge of neuroscience in education can instruct and advise the foundations for healthy student learning, develop well-informed educators, advise parents, and therefore provide well-suited schooling (see Figure 2 and Table 18)

Like the light particles shining on foggy and winding paths, with new technologies at hand, neuroscience now affords us insights into how children best learn, form perceptions, and retain information (Grospietsch & Mayer, 2019; Hennig et al., 2021). There is a great need for an innovative and empirical structure that translates neuroscience correctly to educators (Clement & Lovat, 2015; Coch & Daniel, 2020; Jolles & Jolles, 2021). These academic structures would embody the insights of neuroscience into more effective pedagogy, assessments, and student growth. In addition to applying our knowledge of educational psychology to education, we must incorporate neuroscience and provide proper teacher training on the topic, so that we can make a significant difference by more fully integrating our children's natural processes of learning with their wellbeing whilst promoting teacher awareness and avoiding neuromyths (see Table 19) such as labeling students as "right" or "left" brainer or characterizing them by their "learning styles" and attempting to match them to specific "teaching methods," and differentiating (Goswami, 2006; Grospietsch & Mayer, 2019; Jolles & Jolles, 2021; Rato et al., 2022; Torrijos-Muelas et al., 2020).

Figure 2

In Practice Matrix



Note. Based on the work of Chang et al., 2021, this matrix illustrates the differences among professions that utilize neuroscience in their practice.

The current public educational system with its structure of the Common Core, standardized assessments, and teacher training and evaluation, has strengths based on performance outcomes, but it was not made to meet the needs of all learners to the extent that is required for students to be effectively engaged, happy, and successful (Cognia, 2022). In my experience, often the diverse needs of students are not effectively understood and well-meaning interventions, therefore, are ineffective. The lack of proper testing, labeling, and misdiagnosing are quite common in the system (Whitney, 2017). For instance, sometimes intellectual disabilities are misinterpreted as lack of English language proficiency in the population of English Language Learners (ELLs). In other instances, students with high Intelligence Quotient may have a disability that is hidden or overlooked by test scores or classroom observations. Programs such as No Child Left Behind and Race to the Top, implemented by the eminent system, have consistently neglected students who have differences in their learning and in their cultures (Whitney, 2017). Many interventions do not solve the problems they aim to address.

In my profession as an educator and curriculum developer, I observe firsthand how teachers are expected to integrate support to diverse learners within the context of their daily routines and in their pedagogical practices. The national educational system aims to decrease the performance gap among students and ensure academic excellence, while preparing them for "global competitiveness" (U.S. Department of Education, n. d). Although the plans implemented within the system are well intended, there are numerous problems leading to major shortcomings such as students' feelings about school and their lack of school engagement, that need to be addressed (Cognia, 2022). These disparities may leave many students behind, parents helpless, and teachers frustrated, further fostering unhealthy school environments.

That said, there is light, lots of it—I hold an optimistic point of view and strive to work in collaboration with the Department of Education, not against it. It is time to turn our lens and elevate our thinking by learning about how the human nervous system functions, and how we can design an educational system that rests on the pillars of neuroscience while incorporating insights from psychology like Vygotsky's (1978) concept of Zone of Proximal Development (ZPD), methods of scaffolding, and Piaget's (1976) theories of cognitive development, which we have gained from educational psychology. With this new mindset, our new educational system would exhibit a chirality to our natural ways of learning, as understood by the workings of the human nervous system.

Researcher Positionality

Like the dancing light waves of the electromagnetic spectrum, thoughts oscillate regularly as we interact with our environments. Our opinions and behaviors, thoughts and feelings, form as a result of our interactions with the surroundings, leading to the schema that is gradually constructed in adulthood (Cozolino, 2014; van Kesteren & Meeter, 2020). In my case, when I examine institutions, I look into myself as a divergent thinker and what I have been exposed to in my varied schooling and life experiences, which have formalized my opinions and ethos about education. It was with this mindset that I entered the field of education in 2008. By 2011, I served as the founding teacher at a private school for advanced learners (G &T) and with the curriculum team we formulated a mission and philosophy that led to developing a comprehensive curriculum that is still used at the school today. I transitioned to a public school district because I believe in a free, public education. With excellence in mind, I sought to make my work accessible to other students and teachers, while learning from them.

Culture and belief systems play a fundamental role in how we construct our responses towards places, situations, and people around us. Cultural experiences can act on our neural functions and activate our perceptual processing (Park et al., 2010). In this section, I first reflect upon my own position in both personal and professional domains and examine the variables that influence how I have attained knowledge and professionalism. The value of this reflection has allowed me to uncover the many layers of my own complex thought processes in order to gain awareness of my cultural identity and biases (Minnich, 2005).

To acknowledge my own identity, I am a middle class, White, Persian American woman, mother, educator, writer, scientist, and artist whose experience has been both privileged and hindered in one lifetime. Experience shapes one's perception and informs one's identity, as well as who a person becomes and how they assess new life skills (Snyder et al., 2015). In fact, experiences rewire and change our brains, quite literally (Bennett et al., 2018). The recollection of my varied experiences informs how I connect to teaching and learning. I remember distinct memories at specific times of my childhood and more recently formed associations help me to recall these vivid memories and experiences. I genuinely reflect on these recollections to see how they apply to teaching and learning today. The connectome of our brains and nervous system is much more dynamic than ever thought before (Bennett et al., 2018), driving me to think about divergent methods in our teaching and learning practices.

I posit that life presents us with gifts, treasures I call "wisdoms." I am grateful for my experiences because they have widened what could have been an extremely narrow view. Like others who have experienced both advantages and disadvantages in one lifetime, hard times have helped me to understand how adversities can disrupt children's learning. As a result, I have learned to be flexible and dynamic in my thinking, open to ideas, and creative in my thought process. My life has been a product of hope and I am deeply grateful for it. I know first-hand the problems and challenges individuals and groups who have experienced adversities encounter, especially children. In my profession, children are at the heart of everything, and I am thankful for the ability to be present for my students and their communities and relate to them on deeper and more empathetic levels.

The examination of my sociocultural perspective is a reminder of the experiences in the diverse social and cultural conditions I have observed and continue to live through. These profoundly influence my perception and the personal values I have attained; in that I hold an optimistic view through a creative lens in exploring solutions to help the educational system. Indeed, I am a living example of how one person can in one lifetime replace fear and anxiety with courage and confidence, war with peace, and separation and loss with affection and empathy. My brain is filled with positive thoughts and my heart is full of love and hope for children everywhere. I strive to avoid a deficit view because I believe with the necessary knowledge of neuroscience and research, with good intentions, in partnership and collaboration, we can and will meet the needs of our students.

As a researcher, I think critically and hold an objective view in this dissertation. This perspective helps me to stay “factual” (Levitin, 2016) based on the examination of the provided quantitative data and neuroscience research, while striving to avoid inaccuracies. In this analytical perspective or “scientific investigation mode,” (Levitin, 2016) standardized measurements have been collected, peer-reviewed research has been selected, and when available, meta-analyses have been chosen in support of this study.

The Importance of Neuroscience

There is much to be gained by understanding and applying neuroscience to education. Identifying the connective tissues that bind the two fields can support students’ learning experiences and enhance their social-emotional wellbeing. The knowledge of neuroscience can transform the ways in which teachers deliver instruction, administrators frame their schools, educational organizations such as the Massachusetts Department of Elementary and Secondary Education (DESE) uphold effective policies, and policymakers develop protocols aligned to students’ neuronal structure, function, and potentiality (Buzsaki, 2019; Chang et al., 2021; Choy et al., 2021; Dehorter & Del Pino, 2020). The knowledge of neuroscience can light up the ways in which we think about education. Knowing what we know about the human brain, the nervous system, and its complex processes to date, **in what ways can our educational system use the most recent neuroscience findings to make education accessible to all learners? How can the field of education use the growing knowledge of neuroscience to more effectively meet the unique needs of all learners?**

These questions kindled a light in my mind and guided me to investigate one of the most recent brain research projects which indicates the missing link may be the relational dynamics of the brain between and among people in the classroom, a phenomenon called interpersonal neural synchrony (Djalovski et al., 2021). The exploration of how inter-brain synchrony occurs at neuronal levels illuminates the typical uncertainties we often encounter in the field of education (see Chapter 2). This new body of research is backed by simultaneous, state-of-the-art brain-imaging or hyperscanning, which opens a window into the inner workings of our nervous system at microscopic levels, and the mechanisms of chemical and neurophysiological interactions of our neurons. It allows us to ponder how relationships mediate performance, why certain behaviors emerge, and what it means to apply this newfound knowledge to parenting and in educational settings.

Neuroscience is the light that is crucial for informing educational practices by actively providing and improving training for teachers and staff, developing meaningful pedagogy and measures for assessing students to build effective bridges between home and school by educating all stakeholders. Through the design of a neuroscience-informed structure, educators and parents can afford competent preventive and intervention strategies towards creating healthy ecosystems aligned with recent research on neuroplasticity, healthy child development, and natural growth.

Purpose of the Study

The purpose of this study is to statistically examine existing summative performance data obtained from two grade levels across three academic years from two large and diverse urban schools in order to find emerging connections that can be explained and even translated into the language of neuroscience using an integrative review of novel neuroscience research. The acquired data points include the Next Generation Massachusetts Comprehensive Assessment System (MCAS) for the same cohort of students in grades 3 and 5; Cognitive Abilities Tests (CogAT) in the verbal, quantitative, and nonverbal batteries for grade 3; and WIDA ACCESS for English Language Learners (ELL), collected from large, diverse, urban districts. This study is focused on detecting whether the furnished information such as the Next Generation MCAS and the CogAT relate to one another, if there is growth seen over time, if there are patterns seen in the smaller datasets (for example in the economically disadvantaged, and gender subsets), and how neuroscience can reveal and explain findings beyond performance using the existing data.

The goal of this investigation is to explore patterns and develop insights from the collected public schools' data and relate these patterns and insights to recent findings in neuroscience, exploring the application to the context of education. This study also examines the existing data to see if disparities, such as the inability to meet the needs of all learners in a typical school setting, could be explained.

Once the data is analyzed to identify common networks and/or anomalies, I use the neuroscience lens to illuminate my understanding and apply insights from what we have recently learned from the neuroscience of child development, the neurological processes of learning, and maturation, to the patterns that are revealed through data analysis (Anderson et al., 2019). The knowledge of developmental neuroscience can inform developmentally appropriate parenting, schooling, and emphasize the importance of academic and social opportunities aligned to each stage of development, which can direct us to a new gateway of further exploring the many unique features of cognitive and social development. When an understanding has been constructed, I strive to find meaning as it applies to the field of education.

Guiding Research Questions

This study analyzes two types of summative assessments for the same cohort of students, one of which is the Next Generation Massachusetts Comprehensive Assessment System (MCAS) performance assessments for grade 3 and grade 5, and the other is the Cognitive Abilities-Based (CogAT) data, administered in either second or third grade. Following this quantitative analysis, a neuroscience lens is employed to interpret the findings. Within this inquiry, there are three emerging themes, each of which contain guiding questions focused on my overarching research question, **in what ways can our educational system use the most recent neuroscience findings to make education accessible to all learners? How can the field of education use the growing knowledge of neuroscience to more effectively meet the unique needs of all learners?**

1. **Longitudinal performance:** track students across time to determine the correlation between earlier test scores, later test scores, and growth trajectory.
    (a) What is the relationship between grade 3 and grade 5 MCAS test scores for the same group of students? How do the two districts compare?
    (b) What is the relationship between earlier test scores and growth trajectory observed in the 5th grade Next Generation MCAS performance?
2. **Examination of the datasets**: conduct analysis of available data to examine the distribution of the Next Generation MCAS and the CogAT scores against attributes of

gender, economically disadvantaged, and anonymized school ID across two districts. Only District A provided gender and economic status; therefore, District B will not be included in the analysis for questions 2A through 2F. Both districts provided school information and are therefore included in question 2G.

(a) Are there observational similarities or differences between genders with regards to test scores?

(b) What percentage of the students who were identified as either male or female did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) expectations? What percentage met (M) expectations? What percentage exceeded (E) expectations?

(c) Are there observational similarities or differences between genders with regards to MCAS growth from grade 3 to grade 5?

(d) Are there observational similarities and differences between students identified as economically disadvantaged (EcoDis) and students who were not economically disadvantaged (non-EcoDis)?

(e) What percentage of the students who were identified as economically disadvantaged did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) the MCAS expectations? What percentage met (M) the MCAS expectations? What percentage exceeded (E) expectations?

(f) Are there similarities or differences observed in the MCAS growth percentile from grade 3 to grade 5 with regards to economic status?

(g) What type of growth percentile is observed in each of the districts' schools?

3. **Neuroscience and Education:** use a neuroscience lens to examine quantitative performance data and non-quantitative attributes data to observe how the results can inform neuromyth-free implications related to the field of education.
    (a) Examination of quantitative performance data: What kind of plausible insights from the instruments (Next Generation MCAS and the CogAT) can be reflected in the results?
    (b) Given our current knowledge of neuroscience, how can we use a neuroscience-informed practice in the classroom?

Design of the Study

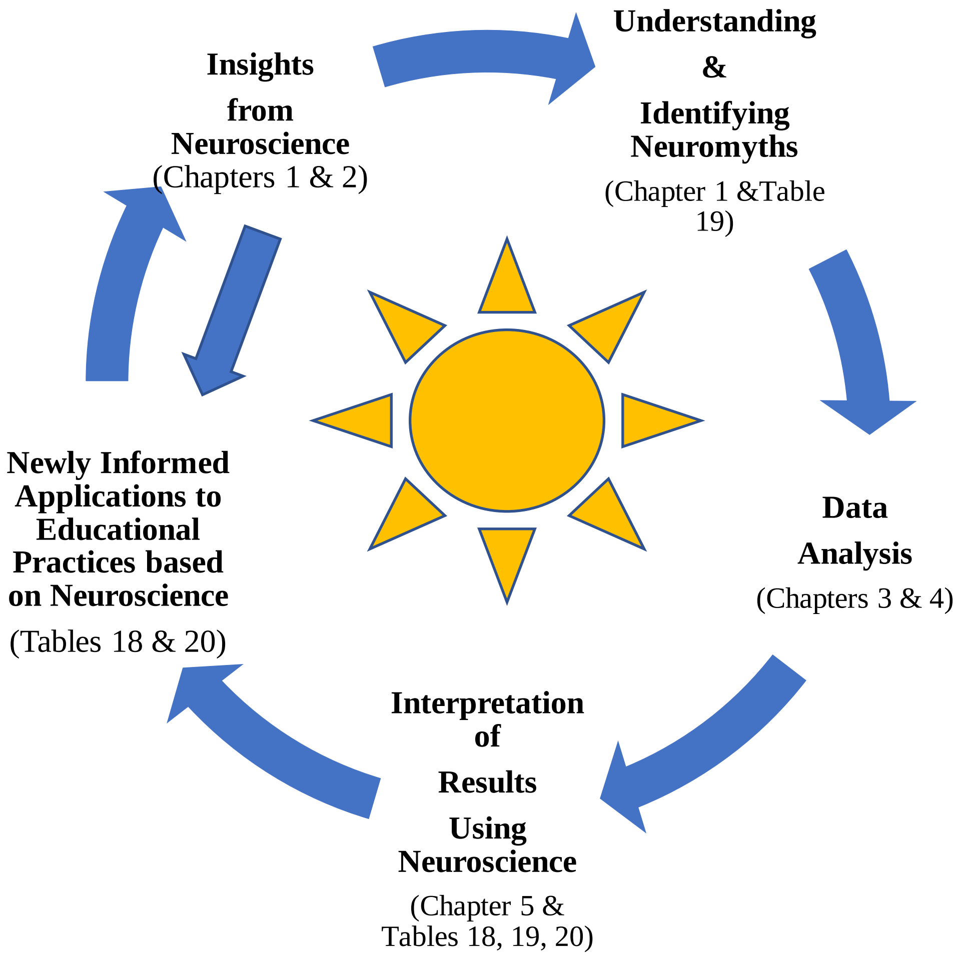
This interdisciplinary study is an empirical mixed methods inquiry that includes extensive quantitative analysis of existing public school data which is further analyzed using a qualitative neuroscience lens developed by synthesizing recent neuroscience research through an integrative literature review (Snyder, 2019). Quantitative analysis is utilized to examine Next Generation MCAS data in English Language Arts (ELA) and Math for the same group of students in grades 3 and 5 and Science Technology Engineering (STE) for students in grade 5, and CogAT test batteries that include verbal, quantitative, and nonverbal domains. Table 2 provides an outline of the acquired data.

In order to widen my lens of inquiry, I selected two large, diverse, urban districts that administered the CogAT in addition to the required standard MCAS testing. The two districts will be treated separately in this examination. As seen in Table 1, District A provided more complete data than District B, for this reason, District B is not included in all the subsections of Question 2.

I chose two large urban districts in Massachusetts that offer advanced academic programming or (gifted and talented) services using the CogAT as a screener for their perspective students. The cost of the CogAT is furnished by individual districts because at this time, the Department of Elementary and Secondary Education (DESE) does not allocate funds for this type of special programming. I selected only districts that could provide the CogAT data, as well as the MCAS data. The data associated with this study is relevant for several reasons. First, the furnished data is representative of data commonly used in the public schools in the Commonwealth of Massachusetts, therefore a close examination of the selected data would be constructive for the participating districts and other public school systems in Massachusetts and beyond. Second, regression analysis of a large dataset of 953 (n = 953), a small dataset of 78 (N = 78), and other smaller subsets within the larger dataset (such as economically disadvantaged students and genders subsets), could inform administrative and teaching questions around the observable disparities. Third, patterns detected in the regression observations could offer insights into emerging findings that may be linked to current summative assessments and student performance, which would be useful for educators. Fourth, examination of datasets could shine a light on the degree of predictability, empowering educators with information needed to better prepare students by offering student-based pedagogy and effective teaching methods. Investigating emerging patterns over a 2-year time period in performance could help to bring to light the underlying neural signatures that could offer insights into the process of learning during specific developmental trajectories. Finally, inquiring about any observable patterns that may be seen in the network with neuroscience magnification, could contribute to the field of neuroeducation in terms of connecting the two fields of neuroscience and education. Figure 3 illustrates the process undertaken in this research.

Figure 3

Cycle of Synthesizing Knowledge



Note. This construct illustrates the cycle of inquiry and synthesizing research in this examination.

Expected Contributions to the Field

This empirical research can contribute to establishing a comprehensive framework that integrates neuroscience in education. Although the new field of neuroeducation or educational neuroscience emerged two decades ago and scientists are cognizant of the need for cohesion between the two fields, neuroscientists still endeavor to build effective bridges between neuroscience and education (Rato et al., 2022; Torrijos-Muelas et al., 2020; Wilcox et al., 2021). At this time, neuroeducation's pursuit to connect neuroscience and education does not properly align with the latest research findings in the field of neuroscience and educator training, hence leading to the emergence and perpetual existence of neuromyths in the field of education. The Organization for Economic Cooperation and Development (OECD) has identified many misunderstandings about the brain and neuroscience amongst teachers and educators (Torrijos-Muleas et al., 2020). Some examples include “learning styles” and the construct of “right and left” brainer (see Table 19). It is no surprise that neuromyths are floating around in the field of education, in published books purchased by schools and used by teachers, and in children’s literature acquired by libraries and parents, further feeding into a false and growing business model. According to Torrijos et al.’s (2020) investigation of two decades of publications of research on the topic of neuromyths, it is found they are still in use mainly due to the absence of scientific knowledge in schools and the missing communication link between scientists and teachers. Some believe it is the business of psychologists to make the necessary connection between the two fields (Coch & Daniel, 2020; Wilcox et al., 2021), while others in a very recent study in Portugal (Rato et al., 2022) found that although educators were eager about brain research, their understanding and resources were not meeting scientific standards.

Based on these studies, my research shows how the knowledge of neuroscience can inform pedagogical practices through statistical analysis. Understanding the neural networks and workings of the brain and the body helps to explain how information is processed, thereby informing how milestone behaviors are interpreted in children’s growth trajectories (Choy et al., 2021; DeSalle, 2018; Goswami, 2006; Klingberg, 2013).

Supporting parents and children in the school setting can be informed by the knowledge of neuroscience. This study applies novel parenting and classroom research that documents neural synchrony and entrainment (Buzsaki, 2019; Dikker, 2017; Koster et al., 2017; Leong et al., 2017; Levy et al., 2020; Lindenberger et al., 2009; Lumsden et al., 2014; Markova et al., 2019; Nguyen et al., 2020a; Nguyen et al., 2020b; Nguyen et al., 2020c; Santamaria et al., 2020) guiding us toward developmentally appropriate autonomy and structure necessary in raising healthy children (OECD, 2020) and proper educational settings provided in schools. Investigating and applying these neuroscience findings can transform and elevate our thinking, inform pedagogical practice, and identify cognitive and social-emotional issues before behavioral concerns emerge. In addition, neuroscience affords a new lens to understanding learning differences and disparities in our educational system and can inform the construction of appropriate interventions and professional training.

With the experience I hold as an educator, parent, writer, artist, and scientist, I feel a deep sense of obligation to provide the community with knowledge of neuroscience that connects to the field of education. The possibility of revealing new information from the Next Generation MCAS and the CogAT, and relating it to neuroscience in a language that is coherent, comprehensible, and explicit is necessary to bond the two fields of education and neuroscience. This investigation is of practical value to teachers, administrators, and parents.

Given my distinctive educational and diverse experiential background affording me with a multilevel perspective in various fields, I aim to identify the missing paths in our current educational system and convey the information from neuroscience in such a way that simplicity and complexity of the human nervous system is maintained and communicated to the public. I aspire to transmit my understanding from different angles and at both microscopic and macroscopic levels. The field of neuroscience is a multidimensional entity, a prism that illuminates our thought processes from every angle. Understanding each of the colors and angles of this dispersion is critical to constructing an understanding of the whole, no different from combining the spectrum of colors to see white light.

I feel genuinely connected to scientists, mathematicians, and artists who inspire and encourage my work. I look to thinkers in the fields of mathematics and art, who are formative and help me to guide the key ideas of this dissertation. Using mathematics as the "key" (Hawking, 2002) to enter "the castle of science," (Cajal, as cited in Ehrlich, 2022, p. 27) and utilizing art as a tool to "communicate" knowledge (Da Vinci, as cited in Zollner, 1998), I strive to illustrate my understanding of the field of neuroscience as applied to our educational system. Being at a crossroads is a true privilege and a blessing and it is with this mentality that I endeavor to find the connective tissues that bind the two fields of neuroscience and education.

Definition of Key Terms

- **Chirality-** handedness (mirror images of molecules that cannot be superimposed by conformational changes in stereochemistry).
- **CogAT or Cognitive Abilities Test Form 7**- a type of "abilities-based" summative assessment measuring reasoning ability patterns of verbal, quantitative, and spatial (nonverbal) contained in three test batteries: verbal, quantitative, and spatial/nonverbal. The test batteries are used for identification purposes in some districts that offer programming for academically advanced students.
- **Cognitive ability**- intelligence, mental ability, or "g," that is highly heritable.
- **Cognitive neuroscience-** the role of cognitive neuroscience is to describe the neural mechanisms associated with the workings of the mind.
- **Cognitive bias**- an irrational pattern of thought, false internalized perceptions that exhibit in behavior. Negative cognitive biases form in people who suffer from anxiety and

depression by imposing false, subjective meaning that can influence cognitive processing. Cognitive biases are constructed when there is a pattern of disparity that leads to irrational behavior.

- **Composite score**- this is determined by averaging three scores (verbal, quantitative, and nonverbal batteries' scores).
- **Descriptive statistics**- coefficients that summarize and provide information on given data sets. These can be representative of sample or entire populations.
- **Developmental trajectory**- patterns of behavior or behavioral mechanisms observed in development as we age.
- **Economically disadvantaged students** - defined as students who "face more learning challenges than students from more affluent households," and qualify for one or more of state-administered programs: The Supplemental Nutrition Assistance Program (SNAP), the Transitional Assistance for Families with Dependent Children (TAFDC), the Department of Children and Families' (DCF) foster care program, and MassHealth (Medicaid). Currently these students' families live "at or below 133 percent of the Federal Poverty Level (FPL), with an annual income of $34,248 for a family of four." All confidential data is protected and follows the state's security policies (DOE, 2015; Massbudget, n.d.; USDA, 2018).
- **Edges**- links that connect the nodes in a graph which is used in graph theory, a novel way to analyze relationships in neuroscience (Farahani et al., 2019 & Gignoux et al., 2017).
- **Educational psychology**- a branch of psychology that studies how humans learn and retain knowledge in schools based on observed behavior and performance.
- **ELL students**- English Language Learners.

- **Emergence-** when functional individual entities come together collectively and self-organize to create patterns or behaviors in complex systems.
- **Entrainment**- brainwave patterns in synchrony with each other.
- **Formative assessments-** these are quizzes, tests, check-ins, and exit tickets to assess how a student is learning in the classroom while discussing a lesson or throughout the lesson.
- **Genetics**- the branch of science that is concerned with genes and heredity, how traits are passed on from parents to offspring.
- **Hyperscanning-** a method used to measure the brain activity of two or more individuals at the same time. This method has been used in recent years to explain neural synchrony in social context.
- **IEP or Individualized Education Program**- a detailed legal document developed for students who need moderate to severe special needs services and attend the public school system. The plan is developed by the school's personnel and the student's parents.
- **Integrative review**- an objective examination that investigates, synthesizes, and compares evidence from literature reviews.
- **504 Plan-** a learning plan used in public schools for students who need additional accommodation in the classroom in order to help them learn. These minor accommodations may include extended time on tests, preferred seating, using a keyboard in place of writing by hand, etc.
- **MCAS or Massachusetts Comprehensive Assessment System (Next Generation)**- a type of summative assessment in public school systems evaluating students' mastery on the Massachusetts Curriculum Frameworks standards. Regardless of learning profiles and academic needs, all students who attend grades 3-8 and 10 participate in the areas of

English Language Arts and Math. A passing score on the MCAS is required for high school graduation. MCAS questions go through a rigorous review process (see Appendix C).

- **Mixed methods**- in this paper, this method is described as a type of research that combines elements of both quantitative (data analysis) and an objective integrative review (neuroscience literature review) to conduct an examination.
- **Negative Ecosystem-** a learning environment that is not aligned to or appropriate for healthy child development.
- **Neural Engagement-** the amount of attention that is dedicated to a task during response to a stimulus (can be measured by electroencephalography/EEG).
- **Neural maps**- spatial representation mapping constructed by techniques used in neuroscience to predict the properties and modulations of the brain and the nervous system.
- **Neural synchrony or coupling**- the intra and inter level synchronization of neuronal waves that create elevated levels of engagement.
- **Neurodevelopment**- the role of neurological pathways in shaping the brain's development in specific developmental stages and how these connections influence performance.
- **Neuroeducation-** a new discipline that combines the fields of neuroscience and education to inform educators.
- **Neuromyths**- general misconceptions relating to the brain and the human nervous system, which are caused by misunderstanding of scientifically established facts to make sense in educational contexts.

- **Neuropsychology**- a combination of neuroscience and psychology that examines cognition and behavior.
- **Neuroscience-** the branch of science which examines the structure and function of the human nervous system.
- **Nodes-** vertices in a graph that are connected by edges or links.
- **Nonlinear regression**- in statistics this is a regression analysis where the observational data is modeled as a nonlinear combination of the parameters of the model, depending on one or more independent variables.
- **One-way ANOVA**- the one- way analysis of variance to determine if there are statistically significant differences between the means of three or more unrelated groups.
- **Oscillation-** a repetitive movement variation or the back-and-forth movement of waves detected in the brain by methods of hyperscanning.
- **Percentile-** in statistics, an equal group of 100 may be divided into the values of a specific variable. For example, the 90^{th} percentile pertains to 90% of the population of 100.
- **Phenotype or phenotypic structure**- the physical properties or what is observable in an organism.
- **Psychometrics**- the field of psychology that is concerned with measuring mental processes such as learning and memory.
- **Quantile regression-** in statistics this is a linear regression that involves multiple variables in an effort to predict and describe the scale outcomes of the values.
- **Raw Score**- this is the score that is calculated first based on the total number of questions answered correctly. There are no points deducted for incorrect answers.

- **Regression observations-** in linear regression the observations may contain hidden relationships between a dependent and an independent variable.
- **Salient experience-** an experience that captures one's attention or stands out. This mechanism of attention is essential in the process of learning.
- **Scatterplot-** an illustration of data that depicts the relationship between two variables (data points on x-y coordinates).
- **Sensitive periods of development-** these are certain milestones in development during which experiences have a profound impact on development, and therefore on behavior.
- **Standard Age Score (SAS)-** a normalized age score for all universal scores. This score has a mean of 100, standard deviation of 16, and a maximum score of 160.
- **Stanine-** a simplified score that ranges from 1-9 (9 as the highest score). It is normalized for grade and age groups and provides an overview of a student's academic performance.
- **Summative assessment-** these are larger tests (end of a unit, MCAS) that assess how much a student has learned from a unit or lesson or theme.
- **WIDA Access for ELLs-** an English language proficiency test, which measures students' academic English language skills in sections: listening, speaking, reading, writing, and comprehension.
- **"Wisdoms"** – gifts offered to us by our life experiences (Taraz, 2022).

Overview of the Dissertation

The introduction of this dissertation began with a creative opening, followed by the statement of the problem, research positionality, the importance of neuroscience, the purpose of the study, guiding research questions, expected contribution to the field, design of the study, and definition of key terms. Chapter 2 is a review of pertinent literature in three sections that include cognitive neuroscience and neural synchronization, an examination of High IQ children, and anxiety in children viewed with a neurological and psychological lens. Chapter 3 includes methods and design of study, and Chapter 4 articulates the results and data analysis. Chapter 5 provides the discussion section, future research, and final reflections.

CHAPTER 2: REVIEW OF LITERATURE

Beautiful things whisper the truth...

—Plato

In the late 19th and early 20th century, Leavitt, Cannon, and Leland, three women known as the "Harvard Computers", looked through Harvard's photographic maps of the sky (Sobel, 2016). Dividing the work into thirds, the three women searched their assigned regions individually and repeatedly, eventually mapping 400,000 stars and discovering how to measure the distances among them. Leavitt alone discovered 2,400 variable stars, each one illuminating the sky with its own brightness. At that time, it was the technology of photography that metamorphosed the practice of astronomy where computation was interpreted by examining images on glass photographs. Why was this identification significant? The findings led to Edwin Hubble's revelations, which eventually brought to light the expansion of the universe and more recently led the way to the launching of the James Webb Space Telescope in 2021.

Similarly, after decades of research, neuroscience seems to be in an analogous spot to that of astronomy in the early 20th century, in that hyperscanning tools are revolutionizing the neuroscience field, studying the human brain. Since Cajal's groundbreaking discoveries about neurons, their dendritic spines, and synaptic communication won the Nobel prize in the winter of 1906 (The Nobel Prize, n.d.), research continues to uncover the newfound dynamic networks of communication igniting the brain. Much like the stars that illuminated the night sky when Leavitt and her colleagues peered into the sky, these inner connections of the brain light up our understanding of how it works. Can this novel knowledge of neuroscience apply to the ways in which we educate our students? Is it possible to chart the learning pathways of the brain as Leavitt, Cannon, and Leland once charted the stars? In this document, I seek to relate recent neuroscience research findings to educational problems such as the observed disparities, with the goal of identifying what insights we can gain from neuroscience that can inform our thinking when it comes to improving our teaching and learning practices, first in the context of educating all students (section 1), and then in the context of educating more specific groups of students such as the high IQ (G&T), and children who struggle with anxiety (sections 2 and 3).

Learning deeply about the neural mechanisms of the brain piqued my interest. Embracing individuality and providing targeted support has enabled me to facilitate learning in my own teaching practice, striving to serve each one of my students as shining stars in the night sky. I want to chart and measure their learning processes, as the "Harvard Computers" once charted and measured the stars. With this mindset, I read and investigated literature about children's processes of learning, and eventually, the words of the cognitive neuroscientist Klingberg (2013) resonated with me: "I am convinced that if we are to make any progress, it will be through scientific method and randomized studies. Teaching has been dominated far too much by political opinion and trendy pedagogical whims. No teaching method suits all students" (p. 145).

In my quest to understand brain structure and function—the hidden mechanisms—of the human brain and the behaviors that emerge and manifest as a result, I wondered how insights from neuroscience could contribute to, and even shift our ways of thinking about an appropriate structure of an educational system. A pedagogy that is commensurate with the phenomenon of learning within our current school structure, without negatively impacting the equilibrium of its constitution. Is there a way to build a learning system that addresses the diverse student needs while maintaining a holistic structure that does not lead to fragmentation?

My interest and examination of cognitive neuroscience, neurobiology, and neurophysiology and striving to understand the mechanisms of the brain have led me to believe that learning is a beautiful phenomenon, involving a nexus of connections and communication in both cognitive and emotional processes, whispering the truth. What is the secret to learning and how can the knowledge of neuroscience unlock the mystery? What about the emotional processes of learning? Beautiful whispers of a truth yet to be discovered? Could schools and teachers use this knowledge for the betterment of the educational system, and ultimately for the wellbeing and happiness of our students?

Motivated by the challenges, successes, and opportunities I experienced running and teaching in an academically advanced or a gifted and talented (G&T) program, and by my own deep interest in the process of learning, I used the knowledge of human neuroanatomy and neurobiology, cognitive neuroscience, pediatric developmental neuroscience, and neuropsychology to reflect upon the application of neuroscience, how it can instruct and inform teaching practices by creating an appropriate structural algorithm for our educational system. While there are numerous educational literatures in the field of education making mention of neuroscience, there is insufficient literature that employs a neuroscience lens to view education. This review looks at how neuroscience can inform our understanding of targeted curriculum, pedagogy, prevention and intervention measures in the classroom. It is presented in three major sections that address the neurobiology of learning, the behavioral outcomes of neuronal communication (neuropsychology), and the role of emotional connectivity in the process of learning. The information here demonstrates the neuronal underpinnings of learning, providing valuable insight into how we can teach and structure our educational system.

To build a framework for the topic, I first review the neurophysiology of the human brain cells and the journey they take to become structurally synchronized. In addition to delving into the concept of neural synchrony, recent case studies are examined. I will then discuss the state-of-the-arts technology that allows for detection of the unseen phenomena at cellular levels. I assert that it is imperative to understand the process at the neuronal level before recognizing the importance of how these processes link to an entire system of synchronization. The information here is mainly gathered from literature on neural scanning.

Furthermore, to address examples where disparity is observed within the larger population of students, I have selected two specific groups of students to examine: high IQ students and students who struggle with anxiety. The number of children who struggle with anxiety is currently on the rise. How are schools meeting this challenge and confronting childhood anxiety? How do they provide an appropriate educational setting for their high IQ population? Neurobiology, neurophysiology, and neurocognitive sciences shed light on the two matters. Finally, I will sum up the findings, what they mean in the educational context and specifically in relation to students who are influenced by disparities in our schools, and identify areas in which further research is needed in this field.

Cognitive Neuroscience and Neural Synchronization:
Relating Neurophysiology and Neurobiology to the Classroom

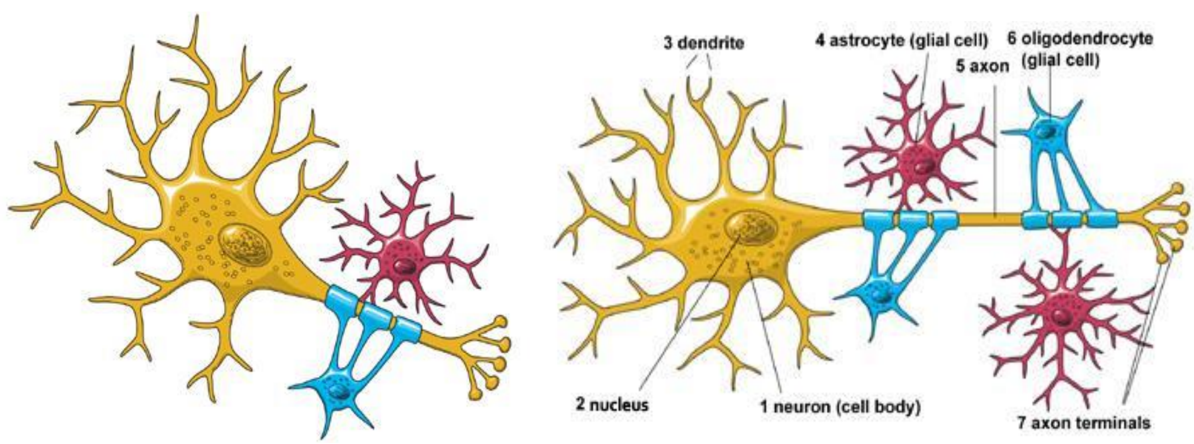
Cognition is a culmination of the mental processes or functions required to attain knowledge by way of consolidating sensory perception, thinking, understanding, and memory or storing information (Cooper & Carlsmith, 2001). The role of cognitive neuroscience is to describe the neural mechanisms associated with the mind. While all the regions of the brain must work together during cognitive tasks, certain regions support distinct mental faculties. We rely on theories in cognitive neuroscience based upon neurobiology, neurophysiology, and computational modeling, in order to understand the underlying mechanisms of the human brain.

Neurophysiology

Neurons are the fundamental units or cells in the brain and the entire nervous system, each one an elaborate, functioning factory with incredible tiny organelles. There are different types of neurons whose central function is communication or transmission of signals. Neuronal communication occurs by means of electrical and chemical transmission of information between the brain and the rest of the nervous system. In addition to neurons, there are other support cells in our nervous system, including oligodendrocytes, microglia, and astrocytes (Figure 4). These cells make up about half the total volume of the brain and the spinal cord, conducting serious functions such as structural support, immunity, regulation, and myelination (a fatty film that protects the nerve cells and speeds up transmission). Embracing the cerebral blood vessels, astrocytes construct the blood-brain barrier and some even function like nerves. They hold small pockets of neurotransmitter chemicals and are responsive to neurons that are within proximity (Turney, 2018).

Figure 4

A Neuron and Glial Cells

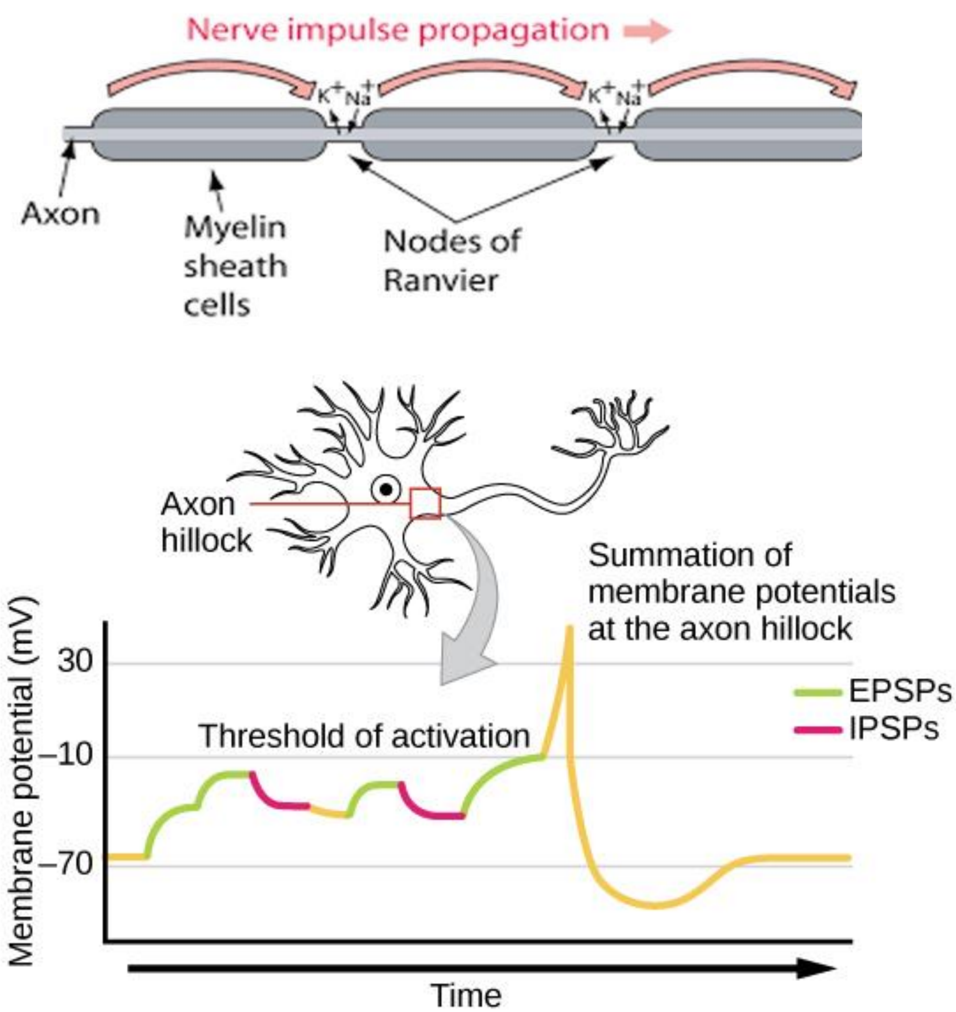


Note. From "Brain Basics: The Life and Death of a Neuron," by National Institute of Neurological Disorders and Stroke, 2022 (https://www.ninds.nih.gov/health-information/patient-caregiver-education/brain-basics-life-and-death-neuron).

Neurons can become excitable when a signal is sent through interactions with our inner (inside the body) and outer environments via our senses. This involves the exchange of ions across the cell membrane (Figure 5). Once stimulated, neurons generate action potentials or electrical activities, transmitting signals from the dendrites of the presynaptic neuron to the cell body of a myelinated axon, toward the synaptic gap and along the dendrites of the postsynaptic neuron (DeSalle, 2018).

Figure 5

Electrical Transmission of Nerve Impulse

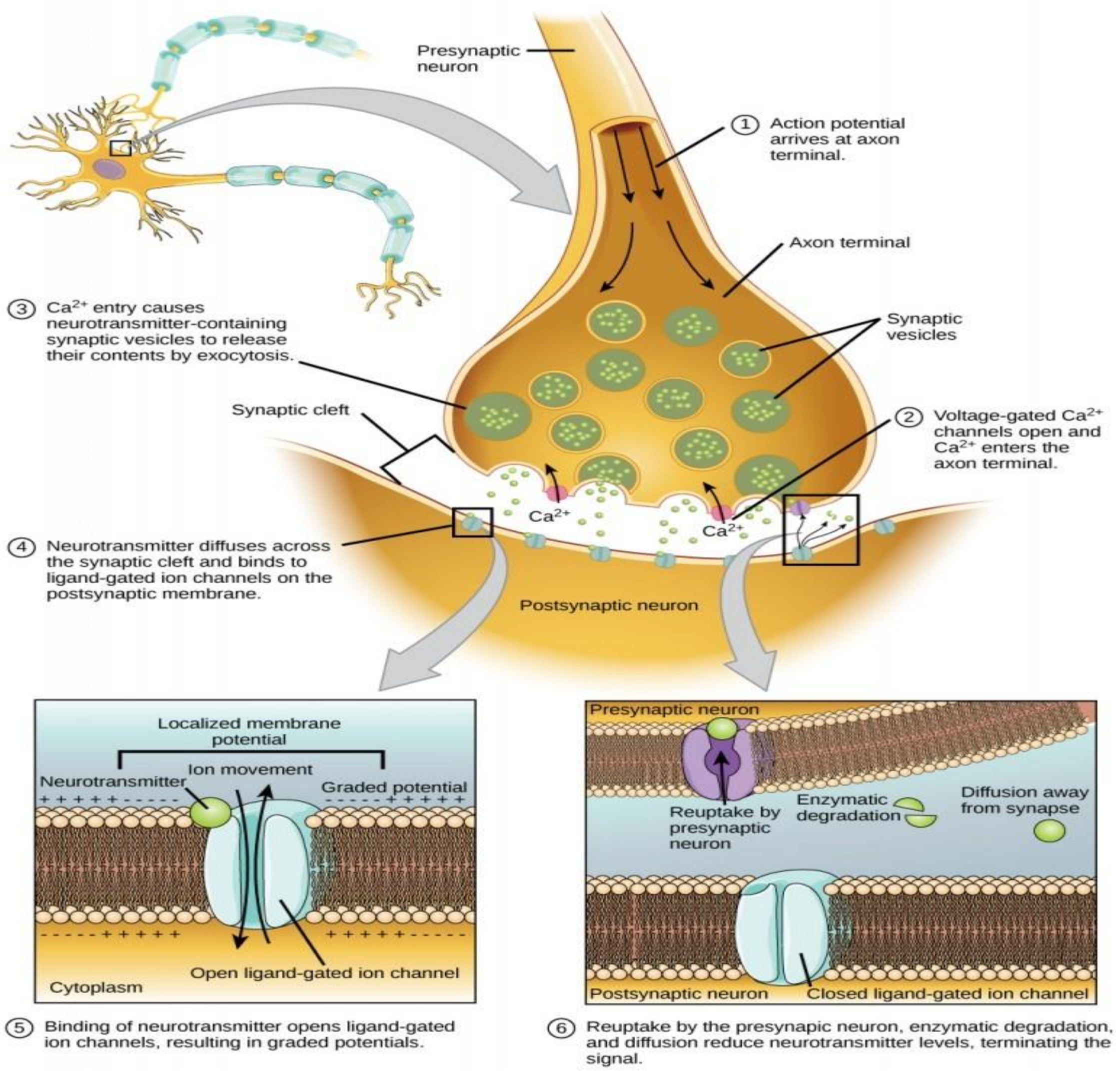


Note. From "Nerve Cells," by K. X., Charand, n.d., Hyperphysics (http://hyperphysics.phy-astr.gsu.edu/hbase/Biology/nervecell.html), and "The Mechanism of Nerve Impulse Transmission" by Libre Text (https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Map%3A_Raven_Biology_12th_Edition/42%3A_The_Nervous_System/42.02%3A_The_Mechanism_of_Nerve_Impulse_Transmission).

Chemical transmission of information takes place in the synapse (Figure 6), exchanging special molecules called neurotransmitters that flow in the synaptic gap from microscopic pockets called synaptic vesicles, across to the receptor of the post synaptic cell whose properties can change due to this transmission. Some popular neurotransmitters include Acetylcholine, Dopamine, Serotonin, and Noradrenaline. What we experience in our emotions, moods, state of mind and well-being are largely impacted by the role of these neurotransmitters and how they are exchanged and transferred. When the amount of neurotransmitters are not sufficient, the results can be attributed to disorders such as Parkinson's, depression, myasthenia, and others (Rapport, 2005).

Figure 6

Chemical Neural Communication Through the Synapse at the Synaptic Site



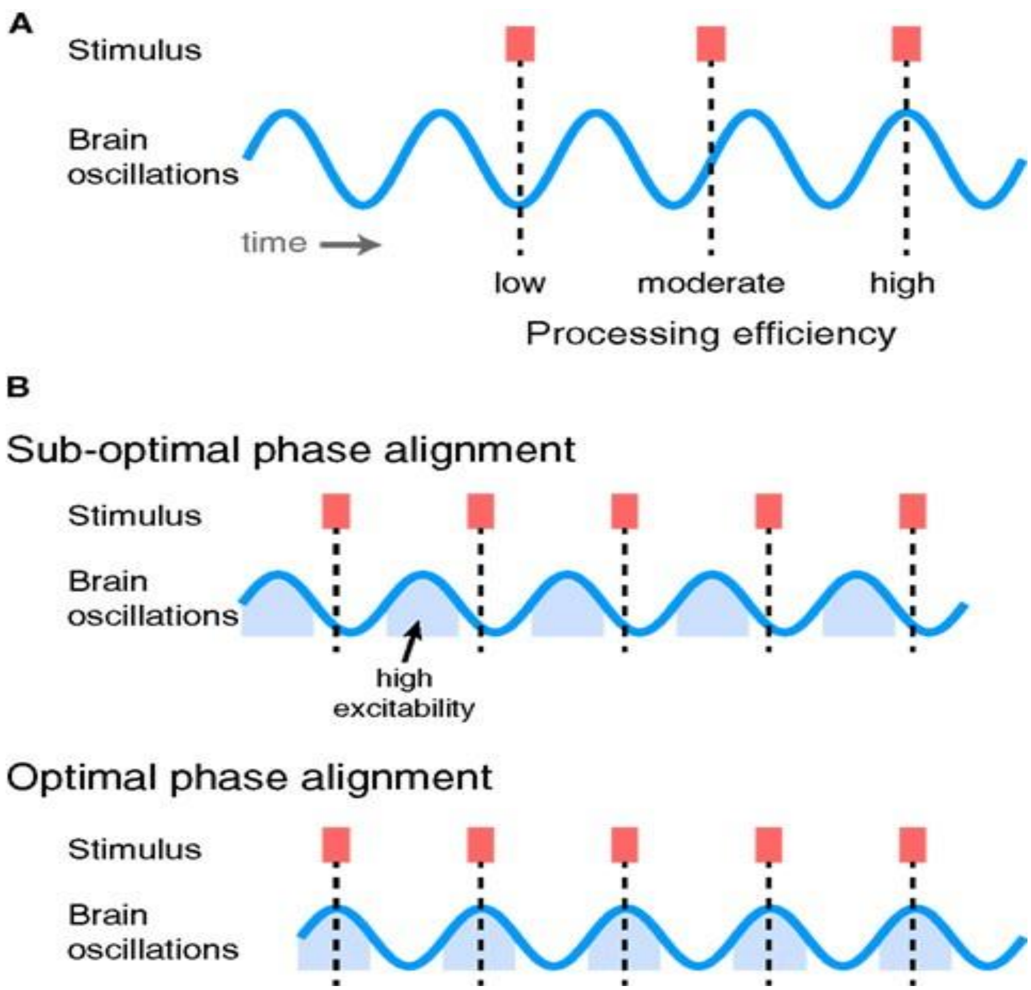
Note. From Press Books, 7.3- Synapses by Sanja Hinic-Frlog is licensed under a Creative Common Attribution. (http://utmadapt.openetext.utoronto.ca/chapter/7-3/).

Neural firing of a group of neurons sends a rush of electrical signals to another group of neurons, creating wavelike patterns and producing electrical activity that can be measured in Hertz. Neurons can physically oscillate both individually and collectively, in a rhythmic pattern. (Figure 7). Also referred to as brain waves, neural oscillations move rhythmically to form repetitive patterns of activity both in and in between the neurons of the human Central Nervous

System (Doelling and Assaneo, 2021). Neuroscientists investigate how these oscillations begin and develop and what role they play in the human cognitive processes. Oscillation activity occurs in different ways. It can be initiated by either mechanism inside each neuron or by the interplay between neurons. As a point of reference, both radio waves and neural oscillations are forms of electromagnetic radiation, which can travel at light speed (Dougherty, 2011). The main difference is in their frequencies.

Figure 7

Ongoing Oscillation Activity in the Brain and its Efficiency in Processing



Note. From "Neural Oscillations Carry Speech Rhythm through to Comprehension" by J. E. Peelle, et al., 2012, *Frontiers in Psychology*, Article 320, p .7.

(https://www.researchgate.net/publication/230843844_Neural_Oscillations_Carry_Speech_Rhythm_through_to_Comprehension).

In recent years, brain imaging has led to the understanding of the mechanism of neural oscillations. Oscillation activity in individual neurons at microscopic level can take place in the membrane potential as patterns seen in rhythmic mechanism of action potentials activating post-synaptic neurons (Doelling et al. 2021). Action potentials are the rising and falling action of voltage that fire up due to the movement of ions through neuron membranes in the cells when they receive signals. The neurons send the message away from the cell body and down the axon in one direction (Figure 5). When there is no signal, however, the neuron is considered to be at rest. During the resting state, the inside of the neuron is negative in relation to the outside.

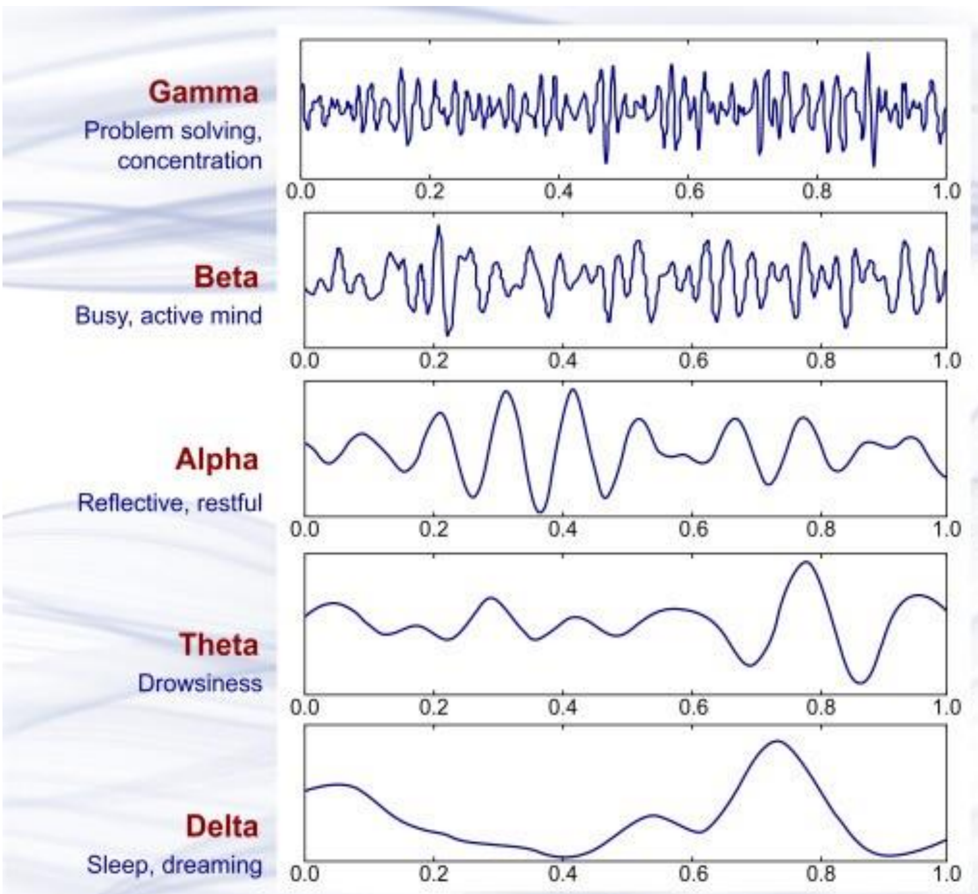
Neural oscillations are characterized by their frequency, amplitude, and phase. Time-Frequency-Analysis is used in recording neural oscillations. Among many neurons, oscillations change based upon synchronization in the "neural ensemble," the ways in which similar types of neurons in a region are organized. While neuroscientists are uncovering the functional role of neural oscillations, they are still seeking answers to what these oscillations mean collectively. The significance of the synchronization of neural oscillations is that they correlate with cognitive functions in the transfer of information, motor control, memory formation, and perception (Carrillo-Reid and Yuste, 2020).

Neuronal oscillations interact at different frequency bands and tend to modulate each other to display specific behaviors. Different oscillation activities may compete or cooperate in such a way that allows for connecting neurons into ensembles and facilitation of synaptic plasticity (Alpha band 8-12 Hz, discovered first in the region of occipital lobe in relaxed wakefulness when the eyes are closed, Delta is at 1-4 Hz, theta at 4-8 Hz, Beta at 13-30 Hz, low

Gamma 30-30 Hz, high Gamma 70-150 Hz- faster gamma band has been connected with cognitive processing- see Figure 8). These brain waves are associated with a variety of behaviors. For example, cognitive processing, consciousness, and awareness have been linked to neural oscillation activity in specific parts of the brain. It is believed there are at least ten specific mechanisms, involving different concentrations of extracellular neurotransmitters, ions, and changes that excite neural cells (Buskila et al., 2019; see Appendix A).

Figure 8

Human Brain Wave Images

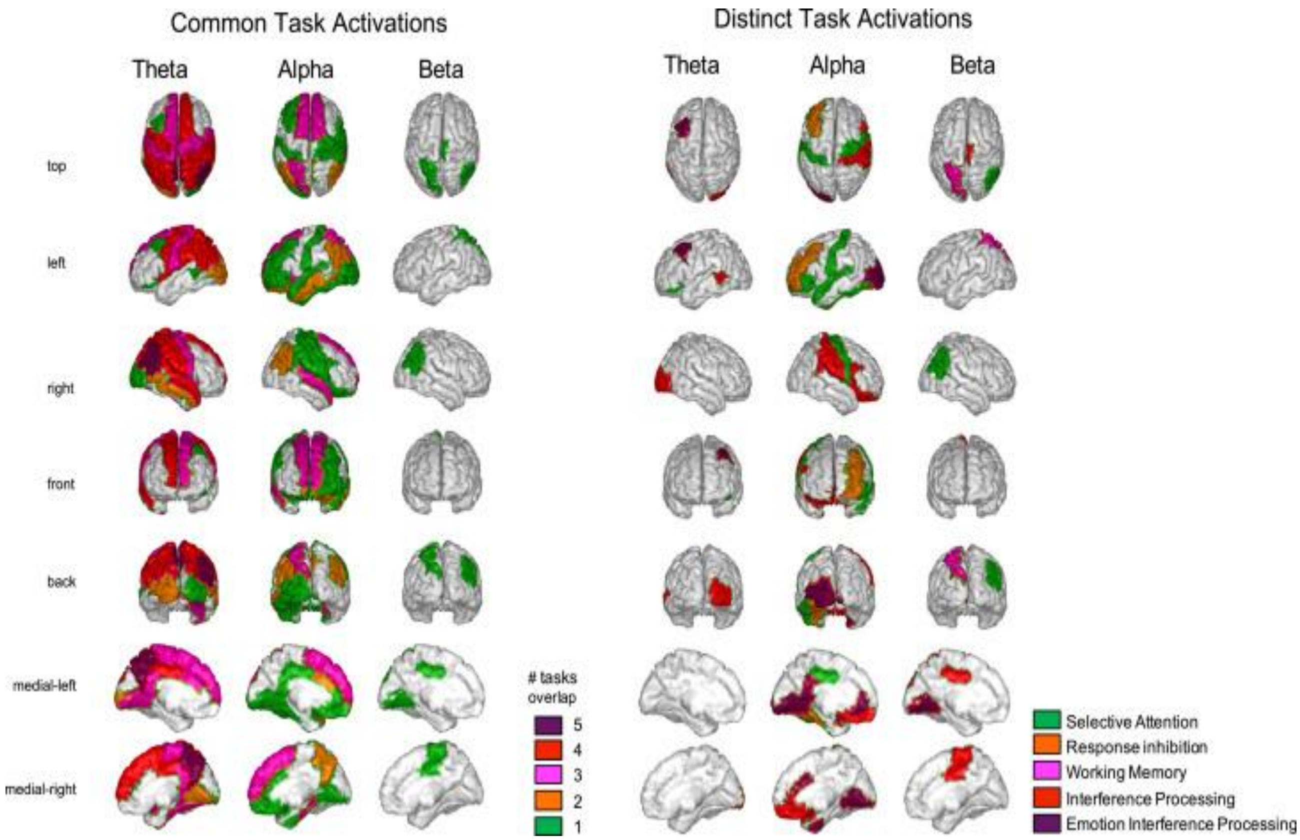


Note. From "Introduction to EEG and Speech-Based Emotion Recognition" by P. A. Abhang et al., 2016. (https://doi.org/10.1016/C2015-0-01959-1). Distinct types of brain waves indicate specific behavior patterns. For example, gamma waves are observed during engagement in intense concentration tasks, while reflective and restful patterns are noted in Alpha waves.

To process information efficiently, a set of vital cognitive abilities are needed. These include selective attention, inhibition of response, working memory, interference processing, and emotion interference processing (Balasubramani et al., 2020). When we are focused on a task, we must constantly evaluate and exhibit cognitive control to suppress distractions and certain behaviors based on feedback. In a recent study, using a scalable platform called *BrainE*, Balasubramani and team (2020) conducted a study that identified the location of specific cortical activation of cognitive tasks using EEG recordings of *BrainE*. It was also revealed that neural responses that were activated during emotional interference displayed a distinct plasticity for a short time. This fascinating research mapped the exact locations of activities during neuro-cognitive processing and identified brainwave bands or neural waves associated with tasks that were examined (Figure 9 and Appendix B).

Figure 9

Cognitive Map With Associating Neural Waves



Note. Specific brain maps display sites during encoding in one or more cognitive tasks. From "Mapping Cognitive Brain Functions at Scale" by P. P. Balasubramani et al., 2020. *Journal of Neuroimage, 231*, Article 117641 (https://doi.org/10.1016/j.neuroimage.2020.117641).

Interpersonal Neural Synchrony

What is the significance of making emotional connections during the process of learning? How does interpersonal neural synchrony in the classroom impact learning? How can we develop classrooms in which interpersonal neural synchrony is optimized for all students? This section delves into the importance of strengthening social threads at home and at school from recent neuroscience findings, in hopes of finding healthy solutions to some of the current societal concerns that children face.

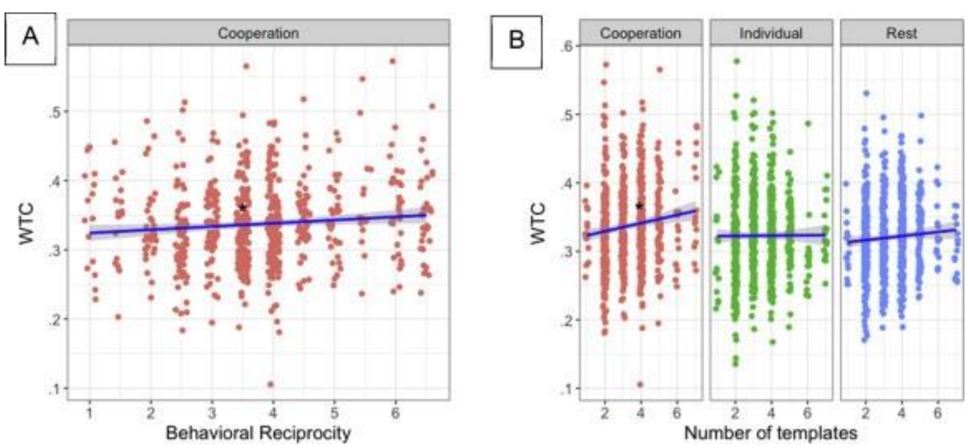
Neural oscillations and their interactions play a significant role in the process of attunement (understanding affect and tuning in to others), as well as cognition. When the elements of oscillation begin cycling with the same period and align to the external rhythmic stimulus, a special process called "entrainment" transpires as a result. Research scientists have uncovered that the optimization of rhythmic (interaction) stimuli due to high neural excitability leads to processing enhancement. In other words, when we are in tune with others or behave cooperatively, our neural processing is optimized, allowing for the ability to predict the information that is coming next, which is the result of the alignment of two or more oscillatory systems. This phenomenon is called neural or inter-brain synchrony (Nguyen et al., 2020a).

Interpersonal neural synchrony is the mechanism underlying effective communication and behavioral coordination. The phenomena of synchronized behavior may be explained by integrating results into three themes: the stimuli, the mechanisms, and the benefits of interactional synchrony. Synchronization occurs at multiple levels of interaction including music, dancing, singing, tapping, coupling of cardiac activity between a mother and a child, in changes seen in pupil size between parent and child, and in the alignment of neural oscillations between two individuals (Hoehl et al., 2021). Positive emotions augment attention and increase flexibility, while negative emotions have the opposite effect, low to no attention and rigidity, indicating the importance of cooperation or interbrain synchrony. This finding is significant to educators, in not only the ways in which they connect and cooperate with their students but also in how they structure and manage their classrooms to promote interbrain synchrony.

Neural oscillations of interacting partners (two people interacting) attune mutually while mediation occurs through entrainment of each participating person's brain oscillations and through the communicative rhythms. What is crucial in understanding this finding in the educational context is the extraordinary discovery that shared information provides a child with relevant information in terms of learning. Information that is shared between an adult and a child can oscillate, indicating the higher the neural synchrony, the higher their behavioral reciprocity, the higher problem-solving task success (Figure 10). This finding demonstrates cooperative connection with others helps to improve our understanding of them (Nguyen et al., 2020a).

Figure 10

Association Between Behavioral Reciprocity in a Mother and Child Study



Note. From "The Effects of Interaction Quality on Neural Synchrony during Mother-Child Problem Solving" by Nguyen et al., 2020, *Cortex*, *124*, p. 240-249. (https://www.sciencedirect.com/science/article/pii/S001094521930406X#fig5)

Graph A indicates the connection between neural synchrony and reciprocal behavior during a cooperation task between a mother and child. Graph B illustrates neural synchrony in different states and task performance. Neural synchronization is involved in emotional regulation and cognitive control development in children. Research suggests that interpersonal neural synchronization is a “fundamental mechanism” which facilitates interpersonal transfer of information in both verbal and non-verbal communication in adults and children. In behavior, the effective transmission of information is connected to both “concurrent and sequential” synchrony (Chang, 2017, 2019; Wilson et al., 2005, as cited in Nguyen, 2020, Atzil et al.2017, as cited in Nguyen, 2020a) relaying that interpersonal synchronization of brain rhythms is actively involved in ways of coordination, communication, and attachment formation between the adult caregiver and the child.

Parental involvement has been connected to emotional regulation, symbolic play, language, and mirroring positive effects helping children understand the link between experiences and facial expressions. Parent-child relationships and their perspective neural synchrony impacts the child’s brain development in structure and in function. Communicative sensory rhythms such as touch or singing and other interactions provided by caregivers lay down a structure that is ultimately the reason behind healthy social development (Nguyen et al., 2020a).

According to Markova et al. (2019), the idea of interpersonal synchrony builds a framework for examining early human relationships, where there is a biological basis. Nguyen (2020b) posits that neural synchronization between mother and child also takes place in a “naturalistic cooperation” task and that neural impact on attachment-based activity constructs the results that serve as a “bio marker” for the interaction quality between the mother and child. Nguyen et al.’s work reveals that maternal sensitivity is critical in the establishment of neural synchronization. Furthermore, mothers who follow the child’s lead can uphold the reciprocity of synchronous interaction longer than mothers who attempt to control it. Maternal sensitivity (their responsiveness to the signals of the infant) affects synchrony and is crucial to infant’s attachment. In the preschool years, this maternal sensitivity to the child will be important for the child's social and cognitive development.

Nguyen's research on paternal sensitivity (2020c) "Interpersonal neural synchrony during father-child problem solving," has been noted the first study in the father-child interpersonal neural synchrony to date, where neural oscillations between father-child are examined. This study found an association at the neuronal level, between fathers and children in the context of interpersonal neural synchrony, highlighting in particular the central paternal role of fathers in the synchronization with their children during problem solving tasks between the father and child dyads. Beyond toddlerhood interactions that are synchronous become more and more symmetric, as children gain social confidence, agency, and communication skills.

Markova (2019) defines interpersonal synchrony as the coordination of an exchange where "hormonal, physiological, and behavioral" cues are switched in a dynamic manner. This can be measured by the behavior demonstrated physiologically, where oxytocin, cardiac output, and even neural levels are considered. Currently there are two known ways that synchrony occurs. Concurrent synchrony involves, "joint action, mutual gaze, mirroring," and sequential synchrony involves "turn taking, reciprocity, and imitation." Dyadic communication rhythms (speech) and external rhythms (music) might be the reasons for interpersonal neural coupling and therefore interpersonal behavioral synchrony. Recordings of brain activities from several people demonstrate that "concurrent" and "sequential" interpersonal synchrony are involved in cooperation with the synchronization of the neurons.

Recent research (Nguyen et al., 2020b) suggests that interpersonal neural synchrony impacts the development of attachment long term. Eye gaze guides social attention in the visual domain. In the visual domain, mutual gaze in interpersonal neural synchronization during free play between mother and child has been noted. In the auditory domain infants directed behavior to facilitate coordination by turning their heads, and in the tactile domain, handholding has been recorded as the first piece of evidence for interpersonal neural synchrony.

Bevilacqua and her team (2019) demonstrate the importance of understanding neural mechanisms in predicting academic performance, and they find a strong connection between attention, interpretation, and retention related to stimulus (content), concluding that student to teacher closeness tends to lead to brain-brain synchrony. Brain-brain synchrony serves as a “neural marker” of participants pointing to the underlying “cognitive psychological processes.” Attachment stimuli such as mutual gaze, head turning, caressing and handholding evoke and incorporate a response that is important in the maturing social brain. The moments of nonverbal synchrony in early childhood during early critical periods within attachment context are the foundations and set the framework for coordination in brain response during social interactions (Levy et al., 2020). In summary, interpersonal neural synchronization between speaker and listener is demonstrating association with greater transfer of information and mutual understanding between the participants. However, further research is needed in this area (Nguyen et al. 2020c).

Lindenberger et al.’s (2009) examination postulates that interbrain synchronization could serve as a representation supporting social interaction and interpersonal action coordination, while Hoehl (2021) asserts the benefits of interpersonal synchrony indicate that behaviors are aligned, and neurophysiological processes are formed based upon the relationships we have. There are many social benefits to interpersonal neural synchrony: predictability, joint attention and action, exchange of information, and a social “adhesive” for affection and belonging.

Experiencing interpersonal neural synchrony leads to effective social interactions (Lumsden et al., 2014).

Case Studies*: Hyperscanning in Support of Interpersonal Neural Synchrony*

Leong et al. (2017) ran an experiment with 8-month-old infants and adult dyads, where the adult recited nursery rhymes with and without eye gaze. This was the first empirical evidence using EEG (electroencephalogram) as the method for hyperscanning interpersonal neural synchronization in adult-child interaction (Nguyen, 2020a). The same year, Levy et al. (2020) ran an experiment using MEG (magnetoencephalography), where 9-year-old children and their mothers watched a previously recorded video of them engaged in positive interaction with both synchronous and non-synchronous behaviors. Neural synchrony between participants was observed in the gamma band during synchronous behavior (Nguyen, 2020a). Gamma waves are indicative of cooperative problem-solving tasks during cognitive processing. This demonstrates reciprocity between the participants.

Atzaba-Poria (2017) assessed interpersonal neural synchrony that studied similarities of parent-child neural patterns and the connection of similarities between parent neural responsivity and child's behavior. Neural activation was assessed over left and right frontal cortices – areas that affect regulation during an interactive puzzle task. It was found that "contingent behavioral responsivity" is essential in the realm of social interactions. This is where both infants and adults are sensitive to responding to one another's signals, a behavior also called reciprocity (Nguyen, 2020a).

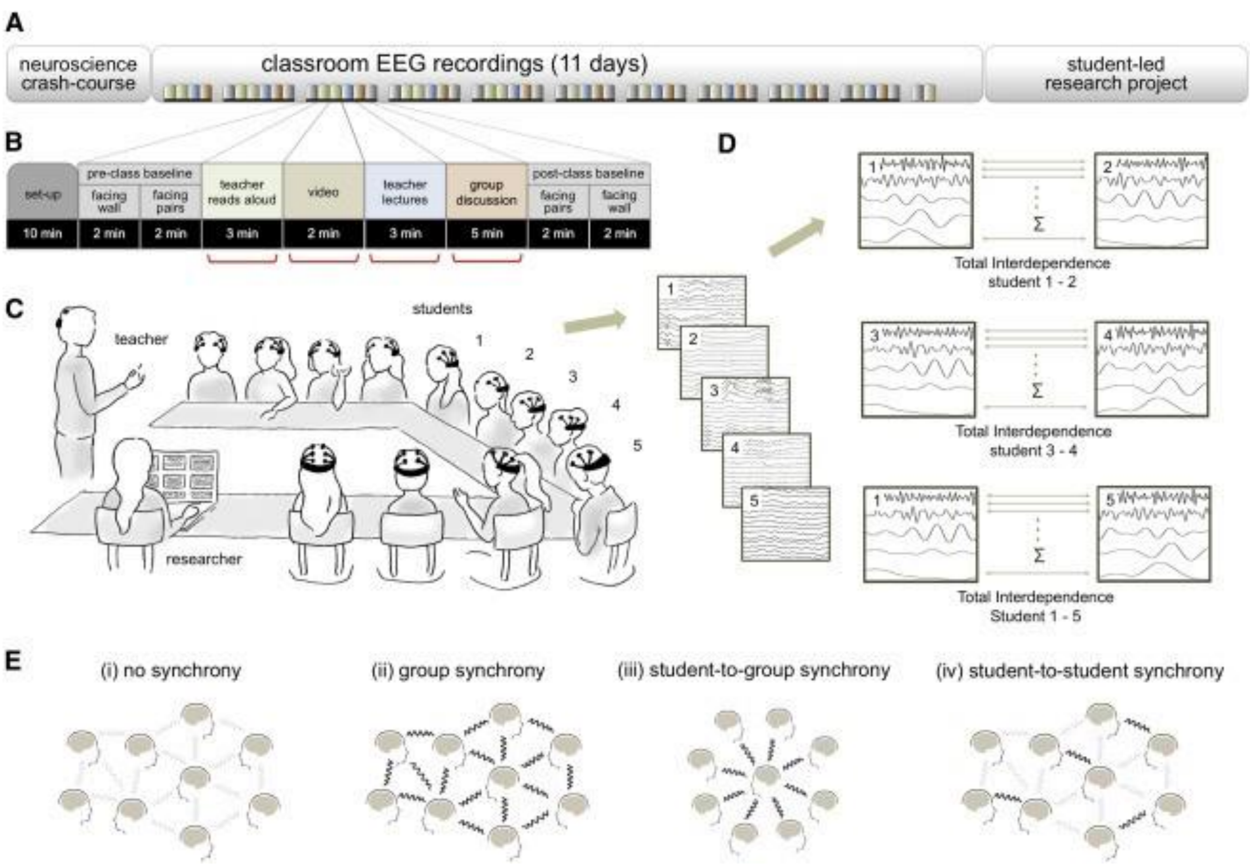
More recently, using fNIRS (functional near-infrared spectroscopy), Nguyen (2020c) investigated neural synchrony between fathers and their preschool children (the study included sixty-six fathers and their pre-school children in East Germany). Father-child dyads indicated an increase in interpersonal synchrony in the region of bilateral dorsolateral pre-frontal cortex, and left temporo-parietal junction in cooperative problem solving. Higher levels of interpersonal synchrony were observed during cooperative interactions that were connected to high-task performance in achieving goals in both adults and children. Children's cognitive development in their father's presence has been linked to better development and higher levels of competence. Father's sensitivity in childcare likely leads to positive outcomes in the child's development. Additionally, the father's involvement exhibited a positive impact on his behavior in providing care, and changes in his physiology were seen. There was a positive association between paternal sensitivity and reciprocity. The results were more successful when the child led the task as the primary agent (Nguyen, et al. 2020c).

In another parent-child study involving children and their mothers, Nguyen (2020b) found interpersonal neural synchrony facilitates communication, the basis for attachment development. Neural synchrony was enhanced when there was direct vs indirect eye gaze. Brain activity observed was located in the central and posterior brain regions in the infant at 3-6 Hz, and alpha 6-9 Hz oscillatory bands, this is the area that has to do with attention and social coordination. Cooperation and communication are facilitated by neural synchrony. In children with autism spectrum disorder, neural synchronization was seen at lower levels.

Dikker et al. (2017) conducted a group investigation using portable EEGs in a classroom of 12 high school students (Figure 11). This research questioned how much of brain-brain synchrony is impacted by stimulus (how content is presented) and how each student's differences impact synchrony. It was found that brain-brain synchrony is affected by stimulus properties such as teaching method (how some teaching methods resonate more with students), and individual differences such as individual student's focus, preference of teaching method, liking the teacher, and personality traits of the teacher and student. Neural entrainment to external stimuli was led by the sum of stimulus properties and attention. Interestingly, this study found that having an empathic disposition (displaying empathy in interaction) can evoke similarities even in the absence of other factors.

Figure 11

An Example of Neural Synchrony in the Classroom



Note. From “Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom” by S. Dikker, 2017, *Current Biology, 27*, p. 1376. (https://reader.elsevier.com/reader/sd/pii/S0960982217304116?token=62876BAFDD029BD094C1F9184E7F8517CF9F724F9880E1943416C26939E80E36FA1CBBCA150D2BEB7D2704B5ECCD8F61&originRegion=us-east-

1&originCreation=20220129013236https://reader.elsevier.com/reader/sd/pii/S0960982217304116?token=62876BAFDD029BD094C1F9184E7F8517CF9F724F9880E1943416C26939E80E36FA1CBBCA150D2BEB7D2704B5ECCD8F61&originRegion=us-east-1&originCreation=20220129013236).

This was a real-world EEG study of a group of 12 students, repeated over 11 sessions. A student's brain to brain synchrony is a prediction of engagement and classroom social dynamics, both of which are crucial to learning.

Another team of neuroscientists conducted group research using EEG as their hyperscanning method, in a senior biology classroom of 12 students. Bevilacqua et al. (2019) established that social closeness between students and teacher raised the level of brain-brain synchrony and content retention during lectures. They compared the brain response in several individuals participating in different tasks such as turn taking in gestures and verbally, and in communicating other person's actions. What emerged from the study was that social factors such as group discussions and empathy toward one another in a real-world group setting predict higher cognitive outcomes demonstrated in students' academic performance. Higher student synchrony to the group was observed based upon the teaching method that resonated with them more, greater focus, affinity with the group, and empathy. This team of neuroscientists identified three motivating factors for brain-to-brain synchrony: stimulus properties (how the content is presented), individual differences, and the social dynamics in the group. In this study, behavioral and cognitive outcomes were measured, attesting to both the level of engagement as well as students' academic performance. Teaching and learning lead to joint action between the teacher and student in a reciprocal exchange (see Figure 16).

Koster et al. (2017) further identified that "intentional" synchrony is more effective than "incidental" synchrony in the educational setting. Their research investigated two groups of students ages 7 and 10. Using EEG as their hyperscanning method, it was revealed that in the educational context, intentional learning of new information enhances the learning process (intentional encoding). Therefore, one can employ strategic processes to enhance the learning outcomes, such as when attention is directed toward a certain stimulus. Prior to this, neuronal oscillatory processes that speak to the hidden workings of intentional and incidental learning in children and adults had not been examined.

Other noteworthy research includes Levy at al.'s (2020) examination of nonverbal neural synchrony using MEG (magnetoencephalography), which records the magnetic field that is produced by neural populations. This technology is known for its temporal precision. The assessment was conducted across developmental trajectories and psychopathological conditions. The analysis informed that the mechanism underneath the sociality is "biobehavioral" synchrony or the capacity to coordinate "physiological processes" between partners during social interaction such as heart rhythm coordination, hormonal release, "salient experiences" seen in combat veterans, neural oscillations, and brain activations. Therefore, neural synchrony can occur even when there is a lack of interbrain communication.

Santamaria et al. (2020) as cited by Nguyen (2020a) provided evidence of modulation of emotional quality and tone of social interactions in interpersonal synchrony. In this work mothers exhibited negative and positive emotions to their infants. Neural synchrony in the infant's alpha oscillatory band- in frontal, central, and parietal areas was detected. The examination showed attuned neural processes for positive vs negative emotions. In the same year, Leong et al. completed an assessment of parent-infant neural synchrony during social learning where 11-

month-old infants and parents played with new toy objects together. Here the infant's social referencing was assessed. It was found that greater interpersonal synchrony with higher phase-locking values-PLV in the alpha oscillatory band at frontal, central, and parietal regions, anticipated higher infant social learning and longer eye contact. In addition, longer maternal speech duration led to an increase in the interpersonal neural synchrony when learning was successful (Nguyen, 2020a). The case studies presented in this section highlight the significant role of interpersonal neural synchrony at all levels of communication.

Hyperscanning

The accumulating evidence to support neural synchronization has been made possible predominantly due to the advances in technology related to brain imaging. Prior to the past decade only studies of single individuals and comparative data found among them guided this research. However, in the last few years the method of hyperscanning has been employed.

Hyperscanning is the simultaneous scanning and measuring of more than one person's brain activity at a given time. Neural scanning methods include fMRI, fNIRS, MEG, and EEG. Temporal alignment of neural oscillations is measured during interactions. Interpersonal transmission of both verbal and nonverbal communication is measured concurrently. Some hyperscanning methods include measures of attention sharing, contingent responsiveness, ostensive signals, and interpersonal regulatory processes, with the goal of anchoring neural to behavioral synchrony (Czezumski et al., 2020).

Hyperscanning is an effective method to study the interpersonal dynamics such as neural entrainment to signals that communicate synchronization of brain activities in interactions between people. The brain activities or oscillation bands are detected using different types of brain imaging. This method has been used in adults and adolescents within groups of three or more that are involved in conversations, playing music together, learning, and teaching (Markova et al., 2019). More recently, hyperscanning has been used in the investigation of parent-child dyads as reported earlier in this section (Nguyen et al., 2020 a, b, c). In Dyadic synchrony neural oscillations synchronizing “reflect” “mutual attunement” through communication rhythms that are interpersonally transferred through the environment, where the sensory system of one person is coupled to the motor system of another. Optimal processing is achieved when sensory input is sampled during “high neural excitability phase” or when the neurons are most excited (Markova et al., 2019).

According to Czezumski et al. (2020) who analyzed existing hyperscanning methods in the past two decades, the oldest and the most common way to measure activities of the brain is EEG (electroencephalography). Novel devices include MEG (magnetoencephalography), fMRI (functional magnetic resonance imaging), and fNIRS (functional near-infrared spectroscopy). There are pros and cons to each of these tools. As an example, fMRI measures brain activity indirectly by picking up changes in activities due to the contrast of blood flow (blood-oxygen level dependent). EEG is considered the best method for measuring activities in the cerebral cortex, and it is economically feasible. In the hyperscanning method, EEG’s temporal and spatial resolution and mobility are valuable (Czezumski et al., 2020).

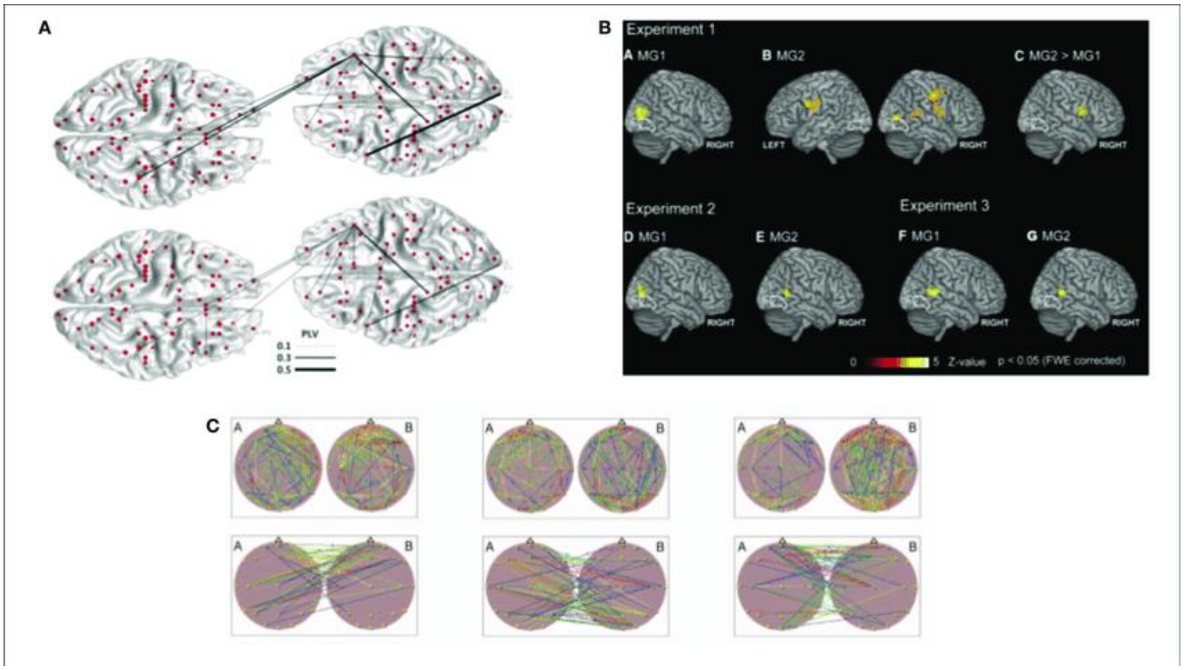
Interpersonal coordination depends upon the synchronization of intra- and inter- level neurons. Intra-brain synchrony refers to neural synchrony within the different regions or domains of one brain. For example, neural oscillation between the cognitive and motor domains, social and sensory, creative and emotional, etc. Inter-brain synchrony refers to brain synchronization (at different domains based upon a given cooperative task or situation) among two or more people at a given time. In conforming behaviors such as problem-solving tasks, we observe toward one another, connect individuals. New advances allow for examining interpersonal synchrony behaviorally, physiologically, and at neural levels.

In the past the neural activity of only one participant in a social scenario was examined but that was inefficient to understand the social interactions at a holistic level. In hyperscanning, simultaneous measuring of numerous brains allows for analyzing different brains at the "intra- and inter brain" activation and neural connections. This technique allows us to understand the complex system of individual and collective actions such as reciprocity, spontaneity, and multimodality (Czezumski et al., 2020). New studies using EEG (electroencephalogram) and NIRS (near infrared spectroscopy) agree when it comes to the correlation between neural synchronization and positive emotion expression and emotion regulation (Lumsden et al., 2014). The use of hyperscanning illuminates our knowledge of relational communication (Lumsden et al., 2014).

Hyperscanning offers a new perspective by detecting reciprocity and dynamics of social exchanges when the dyads are mutually engaged in activities (Figure 12). This technology is giving us new insight into the mechanics of communication and coordination among people. For example, Golumbic et al. (2013) found that listeners benefit from intentionally synchronizing their "auditory cortical oscillations" to the "rhythms of an attended speech signal during verbal conversations" (Nguyen et al., 2020a).

Figure 12

Human Brain Images Using Hyperscanning Method Highlighting Brain Regions During Neural Synchrony

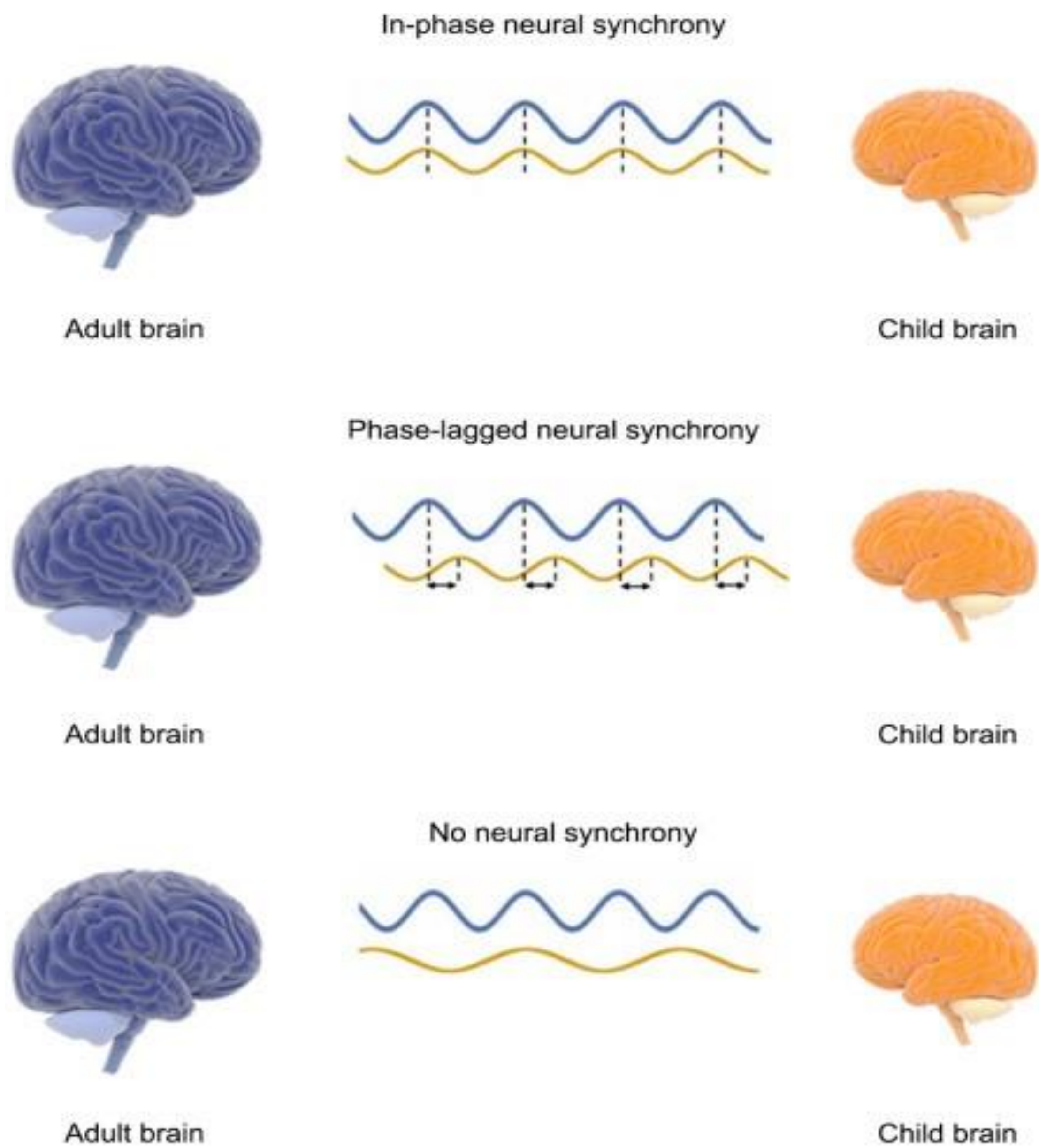


Note. This figure depicts different types of analyses used for estimating the synchronization of brain networks. (A) Theta oscillations (4-7.5 Hz) and beta (12-30 Hz) between two participants, (B) Correlation between brain synchronization, (C) Major intra and inter-brain synchrony. From "Hyperscanning: A Valid Method to Study Neural-Interbrain Underpinnings of Social Interaction" by A. Czeszumski, et al. 2020, Frontiers in Human Neuroscience, Article 39, p. 4. (https://www.researchgate.net/publication/339566369_Hyperscanning_A_Valid_Method_to_Study_Neural_Inter-brain_Underpinnings_of_Social_Interaction)

The areas of the brain that are significant in interpersonal neural synchrony include the dorsolateral prefrontal cortex and frontopolar cortex, which appear highlighted in brain regions during cooperation between the child and adult synchronization activities. Neural synchrony was not observed between stranger-child cooperation which suggests that interpersonal neural synchrony is dependent upon the relationship (Lumsden et al., 2014). Infant-directed singing demonstrates another way of rhythmic interaction with the caregivers that lit up areas in the brain during hyperscanning (Markova et al., 2019). During cooperative problem solving (vs individual), increased neural synchrony was found in the regions of bilateral prefrontal cortex and temporo-parietal areas. Higher neural synchrony and higher behavioral reciprocity were correlated (Figure 13). The results here confirm the role of regions frontal and temporal in neurobehavioral synchronization during the child-caregiver interactions (Nguyen et al., 2020a, b, and/or c).

Figure 13

Interaction of Parent-Child Neural Synchrony



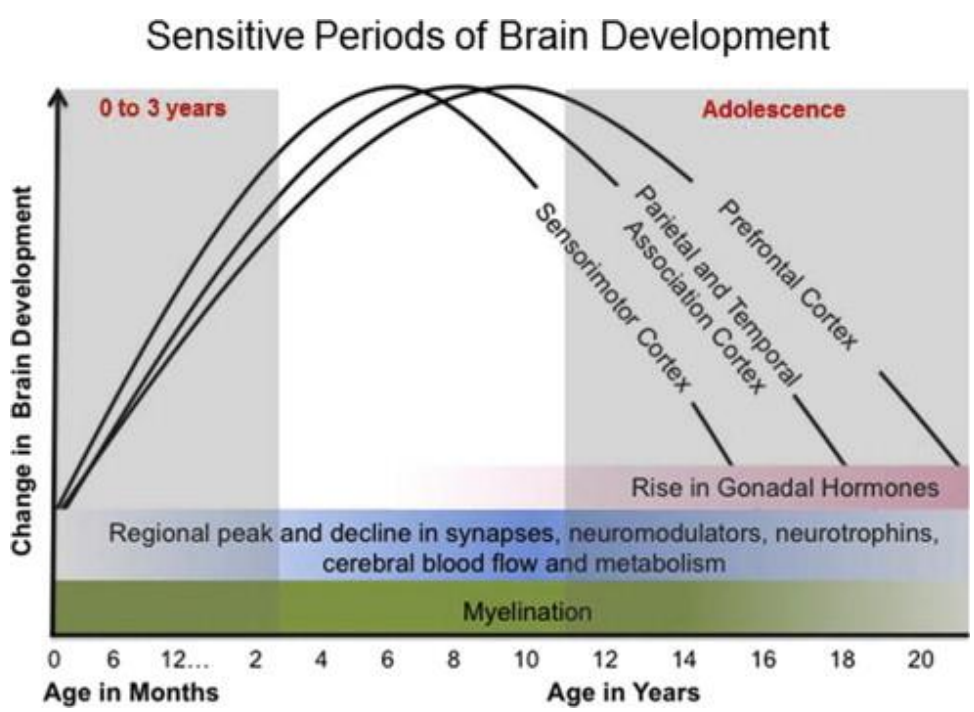
Note. From "Chapter 1 - Studying parent-child interaction with hyperscanning" by Nguyen et al. 2020, Progress in Brain Research, 254, p. 7. (https://www.sciencedirect.com/science/article/abs/pii/S0079612320300455)

Conclusion

Prior to cognitive neuroscientists' recent investigations of the brain at neuronal levels, psychologists and neuroscientists (neuropsychologists) had pondered relational concepts and their impact on human behavior. Through attachment theory (Cozolino, 2014), we know of the importance of forming positive attachment schemas throughout childhood, in particular during the sensitive periods of development. We also know that negative attachment schemas can lead to emotional illnesses that in many cases are irreversible (Figure 14). We now know the secret underpinnings for this aspect of humans are apparent in the deep layers of the folds of our brains, in the neuronal structures, their functions, and the ways in which they operate and communicate.

Figure 14

Sensitive Periods of Brain Development



Note. This figure illustrates the sensitive periods across the developmental trajectory. The gray area shows significant changes in the development of the brain when there is a window of opportunity for behavioral changes. Negative or toxic exposures and experiences at these times can be detrimental to a healthy and sound development

From "The impact of developmental timing for stress and recovery" by D.G. Gee & B.J Casey (2015). *Neurobiology of Stress* (1) 184-194. (http://dx.doi.org/10.1016/j.ynstr.2015.02.001).

Humans are highly complex, social organisms who are built from a microscopic mosaic of cellular structures that are in constant motion and interaction with one another (Cozolino, 2014). What neural synchrony translates to in the big picture or the real-world application, is the understanding that as social creatures we have neuronal webs whose job is to receive, process, and communicate messages. How we achieve attunement, emotional resonance, and sympathize with others is grounded in our brain's ability to connect at neuronal levels. The human brain's processes and nuances are dynamic interactions that go through modifications, adjustments, redevelopment, and rewiring across the developmental trajectory.

In the educational context, neural synchrony or neural coupling is crucial for the exchange of information in social settings. The more frequent the synchronization, the better the task outcomes. Dikker et al. (2017), concede that we as a human species have evolved for group living, yet we know little about the "dark matter" of social neuroscience. She and other neuroscientists provide us with proof suggesting that teaching mannerism, student's differences (in terms of focus, engagement, and personality traits), and social dynamics (in terms of social closeness and social interaction) require attention at neural levels. This impacts students' neural entrainment to their environmental sensory input: the teacher, a video or other stimulation, and each other. In other words, what happens at neural level can be profound in informing educators how to revamp and improve their pedagogy.

The current state of our education is not aligned to this novel science of brain research, as this new field has not yet led to new practices, but insights are emerging. The recent findings discussed in this section of review of literature uncover many aspects in the behaviors expressed in learning, in social development, and in emotional milestones as to how children develop their self-concept. The schemata children perceive, and construct are indeed based on their relationships or relational schemas.

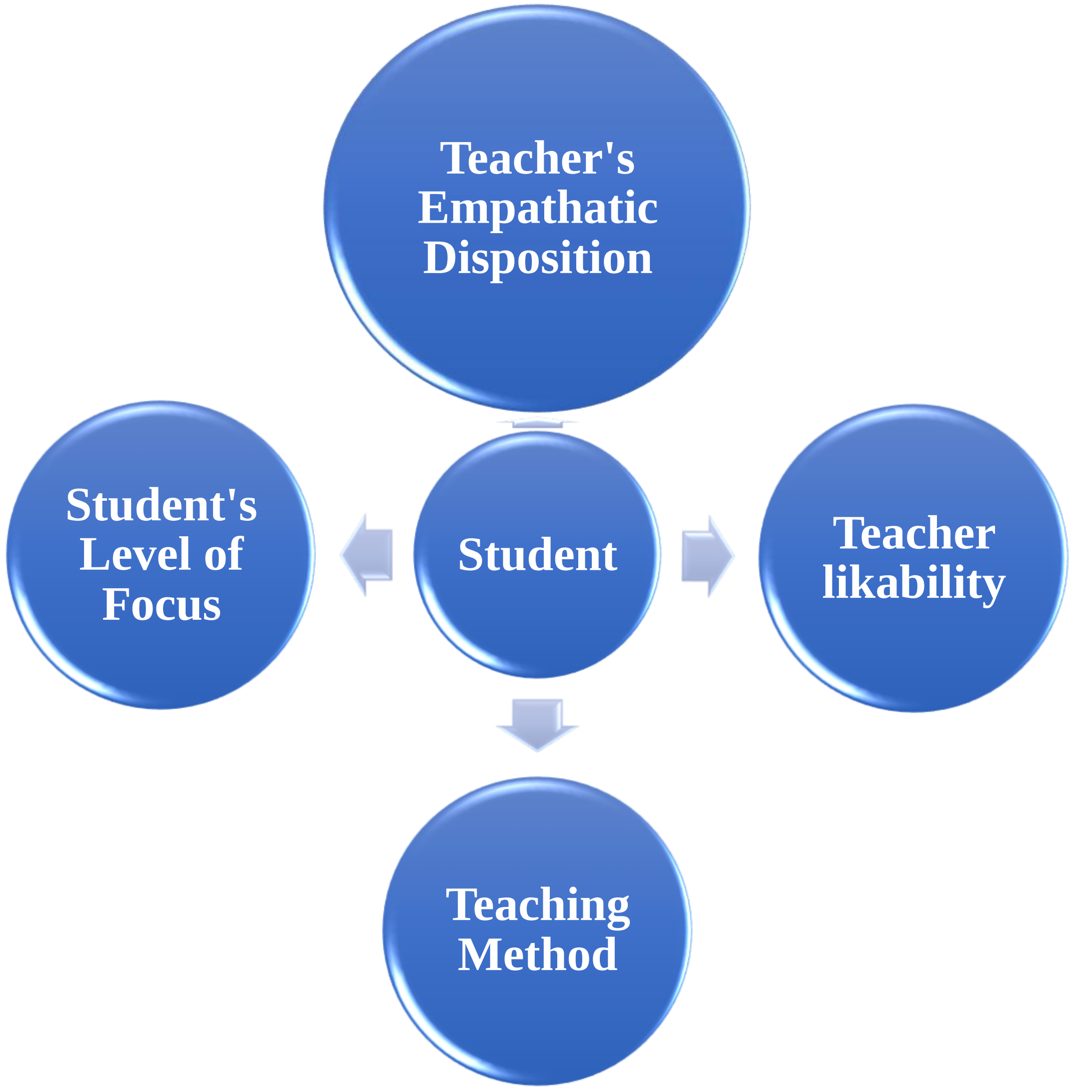
According to Cozolino (2014), learning is a process, and in order to learn positive things, one must be free from fear and anxiety. People need a sense of feeling safe before they can connect. While this process is life long, it is particularly significant in early relationships that construct the phenomenon of attachment. There is a degree of interconnectedness at cellular levels, at the systemic level, and in our organism as a whole.

Relationships shape our internal worlds and sustain us. All life comes with rhythms and pauses, like stimuli that initiate depolarization, igniting microscopic action potentials and periods of repolarization, refractory period, and resting state. The rhythms and pauses can be subtle and slow, or loud and extreme and somewhere in between. There is rhythmic activation in the brain that initiates the learning process. Neuroscience is at the very core of our thoughts and who we are as we process and form mental states.

Based on this research, it is my understanding that lack of interpersonal synchrony between and among people creates frustration and feeling of being misunderstood or not understood at all. Fear and frustration develop and increase anxiety (see section 3) and anxiety can impede the process of learning, as seen in the case of the high IQ population of students, noted in the next section.

Figure 15

Brain to Brain Synchrony: How Stimulus Impacts Learning



Note. A construct based on Dikker et al.'s (2017) EEG group investigation, identifying the stimuli that impact neural synchrony, with empathetic disposition affecting the process of neural synchrony the most, which is quite profound even in the absence of all other stimuli.

Neuronal oscillations give birth to neuronal resonance or coupling. The studies analyzed in this section of the review attest to the importance of cooperation, healthy interactions, and display of empathy in social settings. Therefore, the role of parents in early childhood interactions and beyond is crucial in laying down the fundamentals of interpersonal neural synchrony, which augments healthy child development. In the educational context, it is the job of teachers to establish interpersonal neural synchrony with and among their students, and it is the business of school administrators and policy makers to ensure interpersonal neural synchrony is established among their staff and parents who work directly with children. This seemingly small but significant finding must be integrated into classrooms and practiced in teaching to increase engagement and improve learning across all ages (see Figure 15).

An Examination of High IQ Children: Giftedness, Definition and Development

Why is educating the high IQ (G&T) population of students so challenging? Is there an academic and/or emotional disconnect? What are the necessary interventions to ensure appropriate academic and emotional growth for High IQ students? How can the knowledge of neuroscience inform parents and educators of the needs of high IQ children? This section examines some of the challenges in educating intellectually advanced students as an example of educational disparity in our schools. Historically, the controversies surrounding the topic of intellectual giftedness has come at a significant cost to these children, leading to the lack of identification and misunderstanding of the term gifted, and thereby inadequacy in providing appropriate services. When “high-level potential” children are not properly identified in different learning environments (especially those who are underprivileged) they may not receive proper services (Vaivre-Douret, 2011).

In order to avoid misunderstandings over numerous disparate definitions for giftedness in gifted education, and to analyze the field with a more objective lens, this section investigates factors identified in high IQ children (IQ $\geq$ 130), while recognizing the Intelligence Quotient is only one of the many aspects of what makes us human. Origins of intelligence in terms of heritability, environment, and neurobiology are investigated and correlates such as affordances and vulnerabilities associated with high IQ are explored. Finally, interventions to help support the academic and socio-emotional aspects of gifted children are discussed to inform parents, caregivers, and educators and promote appropriate identification and services.

According to Deary (2009), intelligence is a dimension of human psychology, which plays an important role scientifically and socially in influencing life outcomes. At a functional level, the brain's processes (functional by electrochemical signals received from the information that is processed through the sensory system) must work in tandem to solve problems. Cognitive abilities change with age. At the social level, intelligence is one of the best predictors for outcomes in one's education and career. Higher intelligence in people tends to lead to better physical and mental health, longer lives, and fewer illnesses (Plomin & Deary, 2015).

Intelligence is a complex trait in humans, one that is shaped by both genetics and the environment, and laborious to study due to its complexity. Deary (2013) noted intelligence as it is defined and measured in different ways. Comprised of reasoning ability (processing information effectively and making inferences), planning, problem solving (critical thinking), abstract thinking (being able to see beyond the concrete presentation of things, symbolic or "outside of the box thinking") and the ability to understand complex ideas, intelligence is often measured as IQ.

The phenotypic structure of intelligence has been understood, is measured, and is able to be replicated through the field of psychometrics. Intelligence testing instruments, such as Wechsler Intelligence Scale for Children, have proven to hold a high level of reliability and validity (Deary et al., 2009). Intelligence, or "g," can be referred to as cognitive abilities, mental abilities, and IQ. It is highly heritable, and heritability or gene expression increases with age. Morphological or structural changes take place in the brain as children develop in their environment. Both genes and the environment influence these changes, meaning that both hereditability and environmental factors play essential roles in shaping the structural and functional organization of the brain. In the case of epigenetics, behaviors and the environment such as nutrition and physical activity, can initiate changes that alter the mechanism of our genes (Heyn et al., 2012).

Gifted young individuals are defined as “students, children, or youth who give evidence of high achievement capability in areas such as intellectual, creative, artistic, or leadership capacity…, and who need services and activities not ordinarily provided by the school in order to fully develop those capabilities” (Federal Elementary and Secondary Education Act, as cited in Subotnik et al., 2011, p. 7). Based upon this definition, Subotnik et al. (2011) asserted that specific talents and abilities in certain areas matter significantly because of the child’s “developmental trajectories,” in terms of where they begin, peak, and end. Therefore, giftedness can vary developmentally based upon potential and the capacity to attain giftedness in one particular area or cognitive domain.

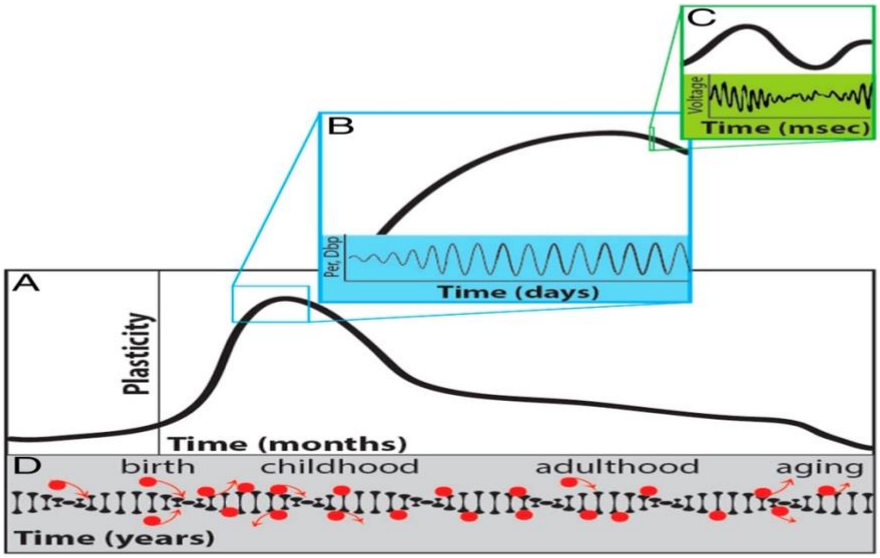
The process of developmental readiness and the trajectories for individual students vary. In other words, all students exhibit certain developmental readiness at different times for varying topics or disciplines and activities. This may also vary slightly in different genders as well across development. A study which examined gender differences in primary school children found that girls performed better in one working memory test while boys performed better in a coordination motor task. Furthermore, academic achievement in the cohort could be predicted based on cognitive and motor abilities that were examined in that group (Zayed & Jansen, 2018).

Neuropsychologists and developmental pediatricians generally look for typical development and growth within specific windows of time. For example, it is expected that around the age of 6-12 months children can sit without help from adults, and they can crawl, reach for toys without falling, look for objects not within their immediate sight, and use strings of syllables to make sounds (Andersen et al., 2019). Later, at around 3-5 years of age, typical children are able to ride a tricycle by peddling, start to draw, exhibit intelligible speech and extensive vocabulary, and play with others. As seen in (Figure 17), the size, mass, and morphology of the brain change during different times of development.

In addition to the range in growth of different types of skills, children go through “sensitive” or “critical” periods where their brains develop and mature at much faster rates, contributing to neuroplasticity (Figure 17). Thus, children make significant gains nonlinearly, in different areas of maturation in various domains such as motor, visual, communication and social functions during these “plastic” windows of time (Figure 16). In recent years, the neural circuit “PV” parvalbumin-positive, a maturing inhibitory neuron has been identified as sensitive to circadian gene manipulation (Reh, et al., 2020). The “PV” cells generate gamma oscillations which are related to plasticity that occurs during sensitive or critical periods of development. Studying oscillations has been powerful in identifying developmental disorders linked to abnormal gamma oscillations.

Figure 16

Critical Periods Across Timescales

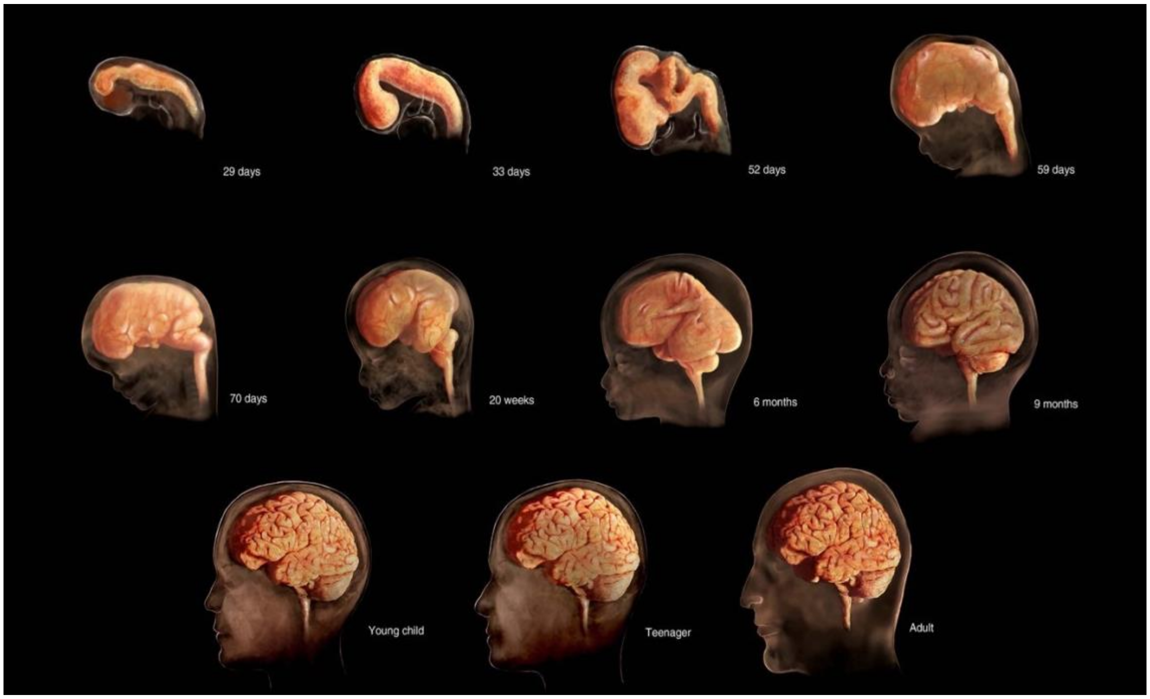


Note. The regulation of "critical period" at different times. (A) Early development, (B) Oscillatory expression of circadian genes with "PV" inhibitory cells emerging- beginning of plasticity, (C) Changes in experience thought to enable plasticity in the circuit, (D) Methylation rates in red circles, throughout development and adulthood. From "Critical Period Regulation

Across Multiple Timescales" by Rebecca K. Reh et al., *PNAS Perspective Biological Sciences, 117*(38), p. 23242-2325. (https://doi.org/10.1073/pnas.1820836117).

Figure 17

The Size, Shape, and Morphology of the Human Brain are Demonstrated at Different Stages of Life From Pre-Natal Period to Adulthood

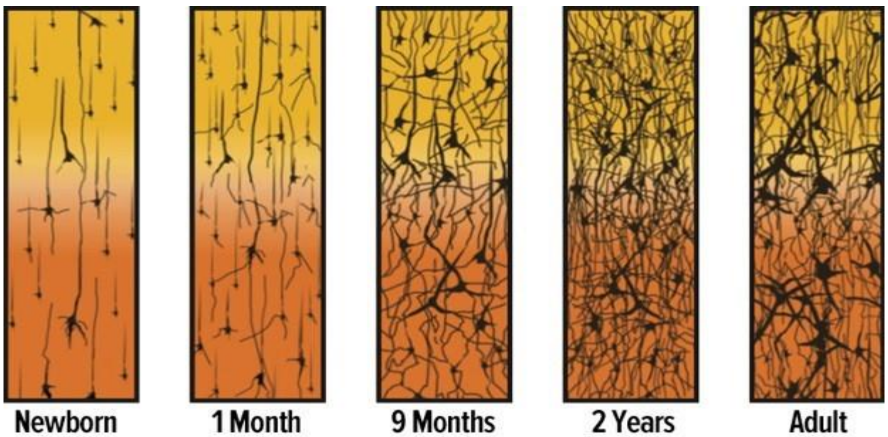


Note. From "The Brain Before Birth: Using fMRI to Explore the Secrets of Fetal Neurodevelopment," by L. Konkel, 2018, *Environmental Health Perspectives*, *126*(11), p. 1. (https://ehp.niehs.nih.gov/doi/full/10.1289/EHP2268).

Anderson, et al. (2019) note that researchers have used methodologies such as observation of change in the brain volume and glucose metabolism to identify the "critical" periods of brain development or "growth spurts". They found that postnatal "critical or sensitive" periods tend to occur between the ages of 1.5-5, 5-10, and 10-16 years and an additional synaptic overgrowth at 16-19 years of age. These transitional stages are notable through observational changes, and significant gains are seen in different areas of cognition, behavior, communication, and emotion. Neuroscientists believe these important phases or "critical" stages in growth and development, during which the brain constructs massive interconnections within the different regions and with other systems in the body, increase brain plasticity and thereby maximize learning while acquiring different types of information (Anderson et al., 2019; Figure 18).

Figure 18

Structure of Neurons and Their Development from Birth to Adulthood



Note. Each panel shows a representation of the number of neurons during the specific developmental stages of life. From "Baby's Brain Begins Now: Conception to Age 3," by The Urban Child Institute, n.d. (http://www.urbanchildinstitute.org/why-0-3/baby-and-brain).

In the case of high IQ children, where their developmental readiness in different domains may vary as compared to the norm, Subotnik et al. (2011) asserted that giftedness is manifested in the children's performance at the "upper end of the distribution in a talent domain" (Subotnik et al., 2011) and that it can vary developmentally based on their potentiality in different talent domains such as verbal, quantitative, or pictorial. Plomin et al. (2015) found that individuals with higher intelligence on one cognitive task seemed to demonstrate higher ability on all other tasks in terms of their ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly, and learn from experience. In psychology, mental abilities are organized according to cognitive constructs of attention, working memory, and information processing speed. Ability is not an easy word to define, as neuroscience informs that human mental processes are quite complex, within which there are many variabilities at any given time (McFarland, 2017). This nature can change based on genetic expressions and environmental factors during development. Therefore, defining ability based on single criteria conveys a much-reduced definition of ability at a particular time. Understanding neurobiology and the difference in developmental milestones and the changes that occur can provide powerful insights into how this knowledge can inform teaching practices. Most teacher training and professional developments available to teachers overlook this significant difference between age-typical and gifted students. Precocity in gifted and talented students is observed in at least one cognitive domain (verbal, math, and pictorial or visuo-spatial).

The Origins of Intelligence

Genetics

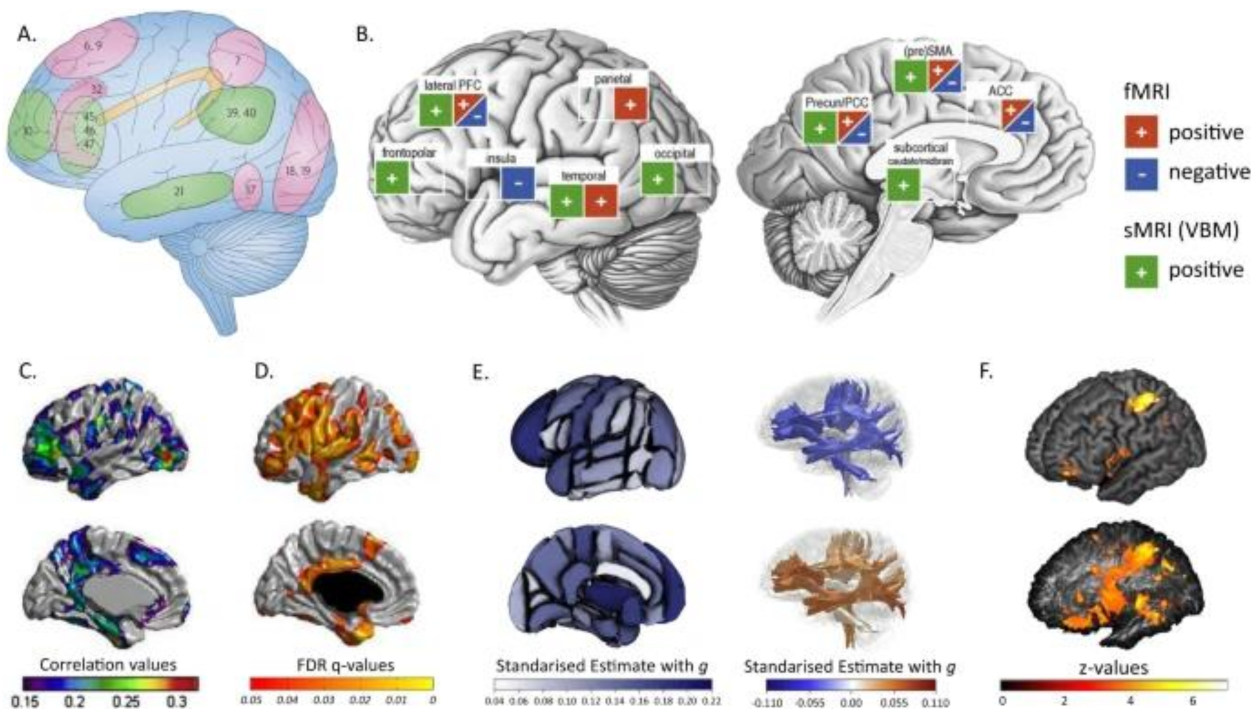
Inquiring about whether intelligence is due to genetic or environmental factors, or both, researchers (Deary et al., 2009, as cited in Deary, 2013) conducted studies to identify the genes that contribute to the trait of intelligence. They found that factors in genetics are responsible for 50% of the differences seen in intelligence among individuals. The remaining contribution to intelligence is the important influence of the environment such as home life, school and education, parenting, and nutritional factors.

Extensive studies of twins and adoption studies over time have found that differences in individuals consistently demonstrate genetic influence of intelligence. Through this research, Plomin and Deary (2015) have identified five genetic findings relevant to differences in intelligence:

1. The expressions of genetic factors go up over a person's lifetime, increasing from 20% in infancy to 80% or higher in adulthood. This means the likelihood of behaving, thinking, or looking like our biological parents goes up as we age (Figure 20).
2. How intelligence and learning are acquired vary associating with how cognitive abilities relate phenotypically (physical properties or the observable) and genetically.
3. It was deduced that there is more "genetic variation" in intelligence than other factors such as one's characteristics and physical traits (Figure 21).
4. The demonstration of intelligence and positive performance expressed at the "positive end of the distribution" curve serves as a model that indicates "positive genetics model refers to intelligence as it appears with a positive end of exceptional performance." (Figure 20).
5. There is a relationship observed between intelligence, education, and the place on the social pyramid in terms of wealth distribution, as well as their interactions and how they add to health, create social mobility, illness, and mortality.

Figure 19

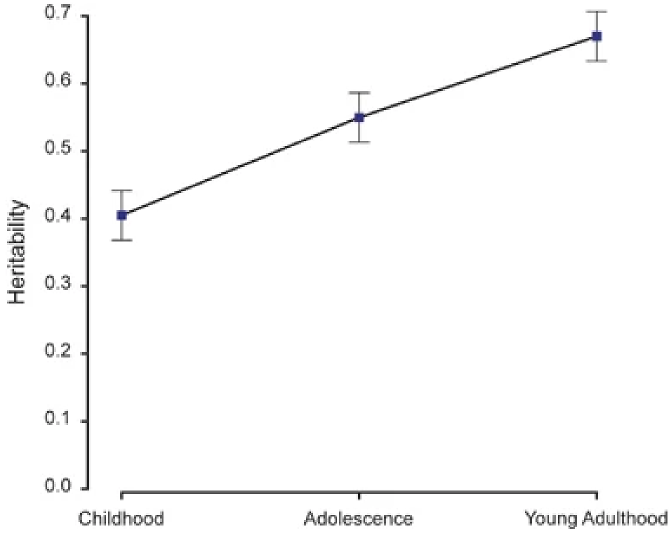
Possible Brain Loci of Human Intelligence Differences



Note. (A) is an illustration of Parieto- Frontal Integration Theory (P-FIT) of differences in intelligence (based on Jung and Haier proposal as cited by Deary et al., 2021), (B) shows functional and structural studies in intelligence in a meta-analysis, (C) indicates the correlation between cortical thickness and intelligence in children ages 6-18, (D) indicates the correlation between cortical thickness and intelligence in older adults, age 73, (E) illustrates affiliation between intelligence and test scores at ’regional cortical volume’ and white matter tract fractional anisotropy- upper right blue, and mean in middle-aged adults, (F) demonstrates how lesion locus and intelligence are associated. From “Genetic variation, brain, and intelligence differences” by Ian J. Deary et al., 2022, *Nature*, n.d. (https://www.nature.com/articles/s41380-021-01027-y#Abs1)

Figure 20

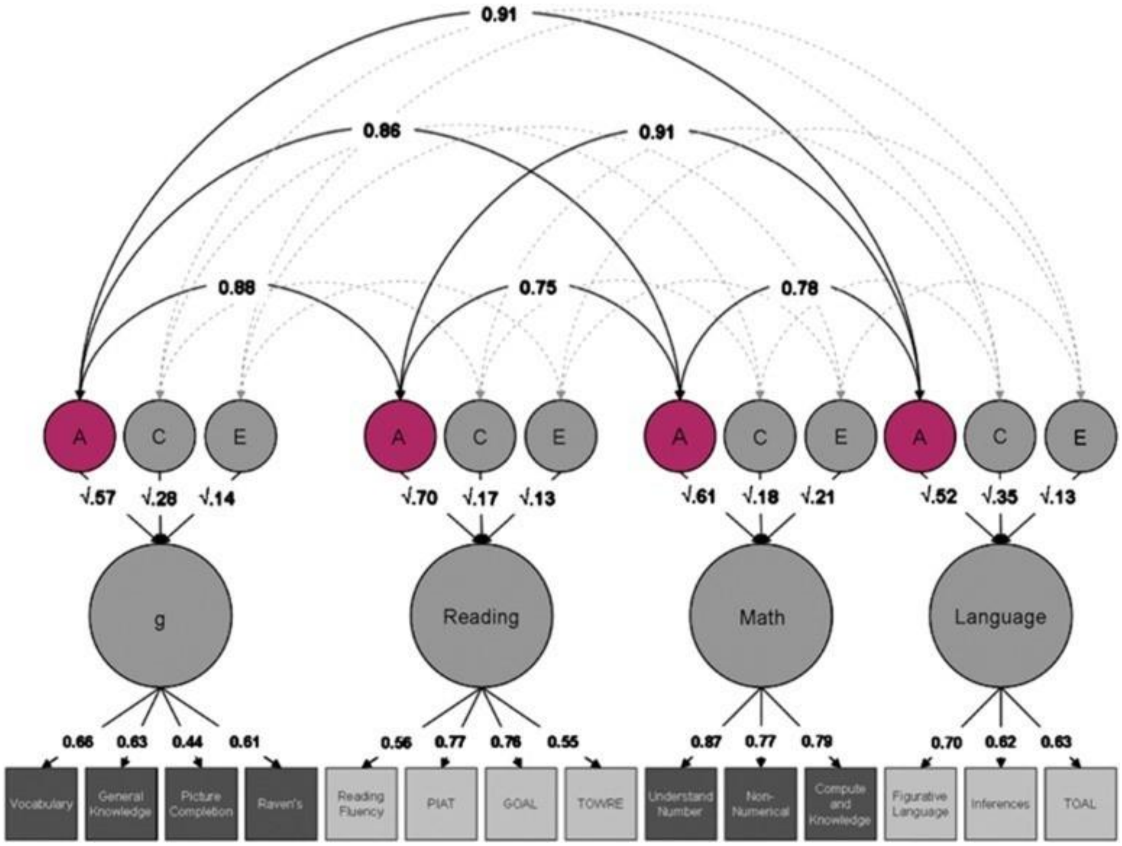
Meta-Analysis Research of 11,000 Twins Indicates That Inheriting Intelligence Increases from Age 9 (Childhood) to Age 12 (Adolescence) and to Age 17 (Young Adulthood)



Note. From "Genetic and Intelligence Differences: Five Special Findings," by R. Plomin & I. J. Deary, 2015, *Molecular Psychiatry, 20*(1), p. 100.

Figure 21

Shared and Non-Shared Environment in Genetic Analysis of Twins



Note. Squares represent measured traits and circles represent latent (hidden or not directly observed, rather inferred through mathematical models) factors. Tiers represent genetic and environmental path coefficients, with the curved arrow showing the correlations between environmental and genetic. (A) is shared or common environmental (C) nonshared environmental (E) contributions to the variance and covariance among the latent variables. These results illustrate the analysis of 14 tests with a makeup of 4 specific batteries: intelligence, reading, math, and language. The study included more than 5000 pairs of 12-year-old twins, indicating that genetic associations between learning abilities and intelligence are equally high-about 2/3rd of phenotypic correlations explained by genetic factors. This excluded uncorrelated measurement error. From “Genetic and Intelligence Differences: Five Special Findings,” by R. Plomin & I. J. Deary, 2015, *Molecular Psychiatry, 20*(1), p. 101.

In order to answer questions as to why some people’s performance is better than others and whether or not performance ability is due to exposure or genetics, researchers (Deary et al., 2009) conducted a study in which over 2000 American children of all abilities participated in taking the Wechsler Intelligence Scale for Children (WISC IV), a popular IQ test that has proven to be highly reliable and valid in testing mental capacity and processing (Deary et al., 2009). The results showed that children who did well on one test did better on all the others, largely due to the cognitive ability factor that accounted for 71% on the intelligence scale. The remaining 28% represented other broad cognitive domains such as verbal comprehension, nonverbal reasoning, working memory, and processing speed. On another WISC IV Block Design instrument that measures participants’ manipulation of two- dimensional patterns without the use of language, the results yielded individual differences to be at 42% due to general abilities, 8% due to nonverbal reasoning, and the remaining 49% due to problems specific to the test. These two examples are of significance to educators because they illustrate that when people are engaged in work, which requires mental concentration, cognitive ability and mental ability, they influence performance within a specific window of time (Deary et al., 2009).

Environment

According to Kentner et al. (2019), in 1964 Diamond demonstrated the observed structural changes in the cerebral cortex of young animals as they responded to input from their environment. In other words, she observed actual neuroanatomical changes in the animal’s brains. While the idea of neuroplasticity had been suggested by Darwin and Hebb prior to this study, Diamond proved the significance of an enriched environment on the growing brain.

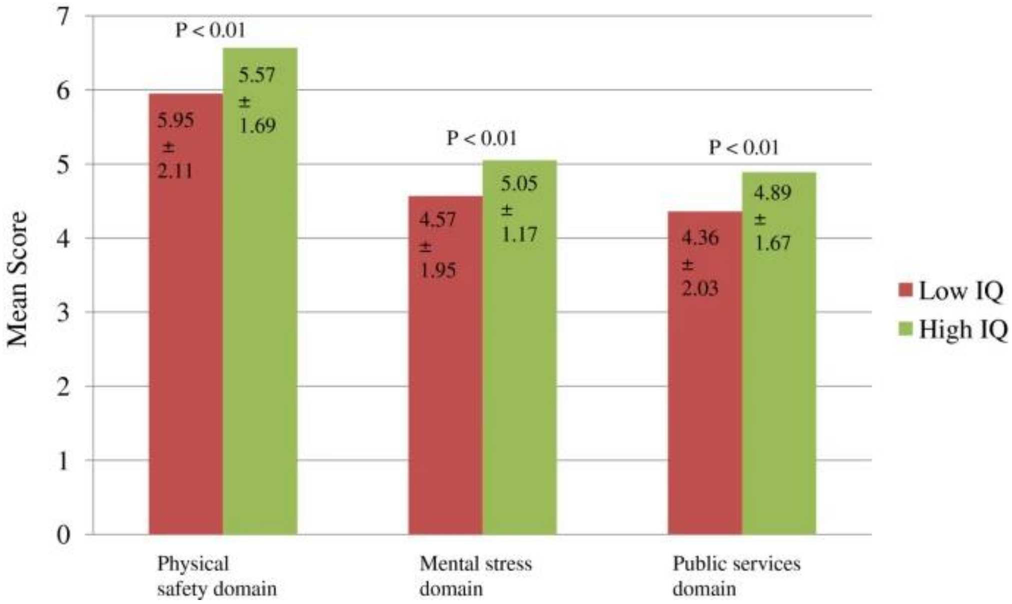
Indeed, the more enriched the environment, the greater the level of engagement on a cognitive task. In contrast, removing enriched environments led to experiencing “loss,” seemingly passive coping behavior, and dysregulation. This finding was more pronounced across the critical or sensitive periods of development when there is an increase in neuronal proliferation. Enriched environments also proved to have therapeutic effects in treating psychological and neurological disorders. Additionally, enriched environments protect cognitive decline in aging brains.

In a cross-sectional study on children in India, in which 1,065 children ages 12-16 from different social strata and a variety of schools participated, researchers Makharia, et al. (2016), found that while genetics plays a key role in IQ, the environment and environmental factors such as neighborhoods, physical activity, family income, parental occupation and education, and socioeconomic factors also have a profound impact on the IQ of children. Children with better environmental factors exhibited higher IQ. As expected, children with lower socioeconomic status exhibited lower IQ. These children have fewer opportunities to develop to their full potential. Parental neglect, malnutrition, and environmental toxins can impair healthy neuropsychological development. Lack of cognitive stimulation, daily exercise, family time, and parental engagement also contribute to lower IQ in youth.

In another study, Ghazi et al. (2012), conducted a cross-sectional examination on 529 children ages 7-8 in Iraq. Economic sanctions in the region, followed by the war in 2003 imposed hardship on families for over 8 years. The study found a significant link between mental stress and the living environment. The authors posited that the effects of war and terrorism profoundly impacted children’s cognitive development. Analysis of factors including feeling safe, mental stress, and services provided indicated significant differences by IQ status (Figure 22).

Figure 22

The Association Between Living Environment Domain (Physical Safety, Mental Stress, and Public Services) and Child IQ Status

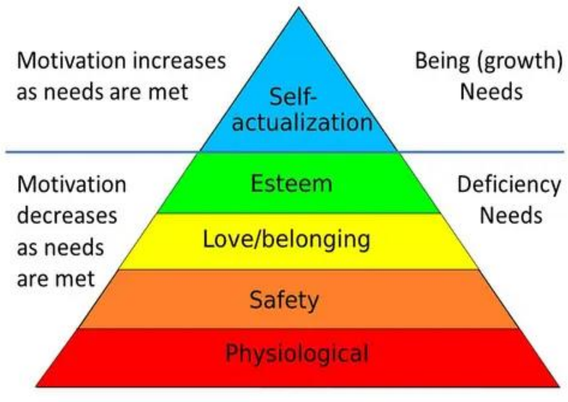


Note. Higher scores indicate better conditions. From "The Negative Impact of Living Environment on Intelligence Quotient of Primary School Children in Baghdad City, Iraq: A Cross-Sectional Study," by H. G. Ghazi et al., 2012, *BMC Public Health*, *12*(562), p. 5.

Looking though a psychological lens, Maslow's theory of motivation (Figure 23) posits that in order to reach higher levels of motivation and self-actualization, the basic needs in the environment must be met (Taormina et al., 2013). In order to grow as an individual, desire and motivation are needed, and the more the lower-level needs are met, the more likely it is for the higher-level needs to be satisfied in an environment.

Figure 23

Maslow's Motivational Pyramid



Note. From "Maslow's Hierarchy of Needs," by S. McLeod, 2020, *Simply Psychology* (https://www.simplypsychology.org/maslow.html).

Chronological and cross-sectional studies in neuroscience and behavioral psychology attest to the significant role the environment plays in the child's IQ, growth, and emotional well-being. It is therefore imperative to provide children with optimal learning environments so that they can reach their full developmental and intellectual potential.

Neurobiology and Cognitive Neuroscience

In the last decade contributions from the field of neuroscience have led to new understandings of human intelligence. fMRI and structural brain imaging have identified different pathways within the neural network providing evidence that parieto-frontal pathways can contribute to the differences in intelligence (Deary et al., 2010). The biological differences in human intelligence were examined through the lens of differential psychology, which studies cognitive and personality differences by accurately defining and understanding the causes and real-life impact of trait differences (Deary et al., 2010).

According to Deary et al. (2013), genetically, “g,” or general intelligence’s heritability, increases with age. Intelligence is like a “small world network,” a complex ensemble of many networks illustrated as a mathematical graph model, where there is an undisrupted flow of information along the white matter fibers. There have been remarkable correlations between intelligence and white matter and network efficiency, inferring that integrity and organizational efficiency of white matter is essential for higher intelligence. The findings provide evidence that more intelligent people display a more rapid reaction to visual and auditory stimuli. There is a strong link between “neural functional efficiency and IQ,” particularly in the parietal and frontal areas. Basic and applied neurosciences can investigate why some brains are more efficient than others, and differential neuroscience has a good foundation from which to move forward and extend to further research (Deary et al., 2013).

In a developmental and cognitive study, Vaivre-Douret (2011), investigated the psychomotor development in gifted children. In previous studies (as cited in Vaivre-Douret 2011) in this field, children with “high level potentialities” and who are “intellectually gifted” demonstrated sensory, locomotor, neuropsychological and language skills early. This French longitudinal study on infants found advanced newborns exhibited the ability for calm wakefulness of 8 minutes versus the 3-5 minutes for typical infants, as well as increased eye gaze, increased alertness, certain sensitivity to all sensory perception, increased intentional focus, and increased interest in the voice of the observer. Before the age of four years, language precocity was observed and there was a particular interest in perceptive visuospatial tasks. In executive function, a 1-2-year display of advanced planning ability was observed. In these children, all sensory perceptions were particularly sharp; a form of intuition or “sixth sense”-with excellent processing ability, analytical processes, the ability to look for strategies, eagerness, and curiousness about everything was observed. The children were ready to experiment and innovate while displaying creative skills in game construction. Of note was a keen interest in science, books, and metaphysics. This study identified links in the processing of information, including rich vocabulary, attention, memory, cognitive mobility, reasoning strategy, and maturity of the prefrontal cortex.

Biologically, a correlation between IQ and gray matter and lower glucose consumption (less energy required to complete cognitive tasks as compared to typical children) was observed. The correlation between IQ and gray matter, and lower glucose consumption is due to the occurrence of two phenomena, temporal characteristics of neurons de-charging link to properties of the membrane, synaptic interactions, and myelin surrounding the axons. The combination of the two phenomena speeds the transmission of incoming information and can play an essential part in encoding memorization and enabling certain learning abilities with sensorial and/or motor "intermodalities," which lead to extensive cerebral plasticity (Plomin et al., 2015).

In another interesting investigation where EEG studies were used to evaluate memorization. A functional cluster analysis of similar fluctuations was used to demonstrate the differences between gifted and nongifted students in terms of memorization. Researchers Jin et al. (2007) found that gifted students' functional cluster map revealed dominance in the right hemisphere, recognized as a characteristic of the gifted brain, in comparison to average students. The study of 18 high IQ and their typical peers revealed that High IQ students reached a remarkably higher score as compared to their typical peers. This investigation speaks to some of the differences between the two study sample groups' brain processes (Figure 24).

Figure 24

Differences in EEG between Gifted and Average Students: Neural Complexity and Functional Cluster Analysis

Factors	Group	Mean	SD	T	*p*
Fluency	Average	96.25	15.14	−6.296	0.000***
	Gifted	125.42	13.71		
Originality	Average	102.90	20.85	−6.127	0.000***
	Gifted	135.58	11.30		
Abstractness of Titles	Average	87.95	32.63	−1.223	0.229
	Gifted	100.95	33.73		
Elaboration	Average	71.40	16.78	−2.559	0.015*
	Gifted	85.21	16.92		
Resistance to Premature Closure	Average	91.55	21.78	−3.617	0.001**
	Gifted	113.79	16.02		
Checklist of Creative Strengths	Average	11.85	4.86	−2.823	0.008**
	Gifted	15.58	3.17		
Creativity Index	Average	101.40	22.25	−4.491	0.000***
	Gifted	128.16	13.72		

*$p < .05$, **$p < .01$, ***$p < .001$.

Note. This figure shows the EEG comparison between gifted and average students. From "Differences in EEG Between Gifted and Average Students: Neural Complexity and Functional Cluster Analysis" by S.-H. Jin et al., 2007, *The International Journal of Neuroscience*, *117*, p. 1167-84 (https://doi.org/10.1080/00207450600934655).

In a research study on the neurobiological foundations of giftedness, Mrazik et al. (2010) observed unique patterns of advanced intelligence in the areas of right prefrontal cortex and inferior frontal activation in gifted children. In some cases, correlation with abnormalities and behaviors was seen in the development of children. Further exploration into prenatal literature as a part of a constructive model is needed to better understand these patterns in the development of highly intelligent individuals, and the ways in which neurodevelopmental factors are responsible for their unique brain development.

Correlates Associated with High IQ

Affordances of High IQ

There are many dimensions to giftedness and distinct characteristics in gifted individuals. In keeping with the cognitive and motivational factors of learning, a comparative study between gifted and nongifted students was conducted at the high school level. Do gifted students exhibit higher motivation levels? Hong and Aqui (2004) found there were diverse types of giftedness (intellectually gifted, academically gifted, or creatively gifted) and suggest that researchers articulate the type of giftedness that they investigate in their research for more clarity. In this study the "academically gifted" students were those who were high achieving in math, and "creatively talented" students were those who were deeply interested and active in math but did not necessarily show high achievement on tests. Incremental theorists put more emphasis on effort, indicating a positive correlation with achievement. This study showed that "academically gifted" and "creatively talented" adolescents reported higher self-efficacy in applying more strategies to mathematical problems.

There were three related measures observed in the two groups: ability, value, and self-efficacy (Hong & Aqui, 2004). Natural ability demonstrates skills in a cognitive task, value speaks to respect for one's attainment and work, and self-efficacy indicates trust in one's performance. Overall, gifted students were more cognitively competent and more intrinsically motivated than their classmates. They offered more strategies and applied more conscious control over processing the solution and in organizing and transforming the information. This was especially true in the case of "creatively talented" where they did not score as high but seemed to be more cognitively resourceful, showing profound interest in this area. In examining self-regulation and motivation in children with high IQ, Calero et al. (2007) conducted a comparative study where high IQ and average ability students ages 6-11 participated in work requiring two different computerized tasks: “self-regulation and concentration test for children” and “self-regulation.” Self-regulation is related to working memory, action orientation, and self-motivation, which align with concentration. The study found that high IQ children were better at self-regulating than those of average ability.

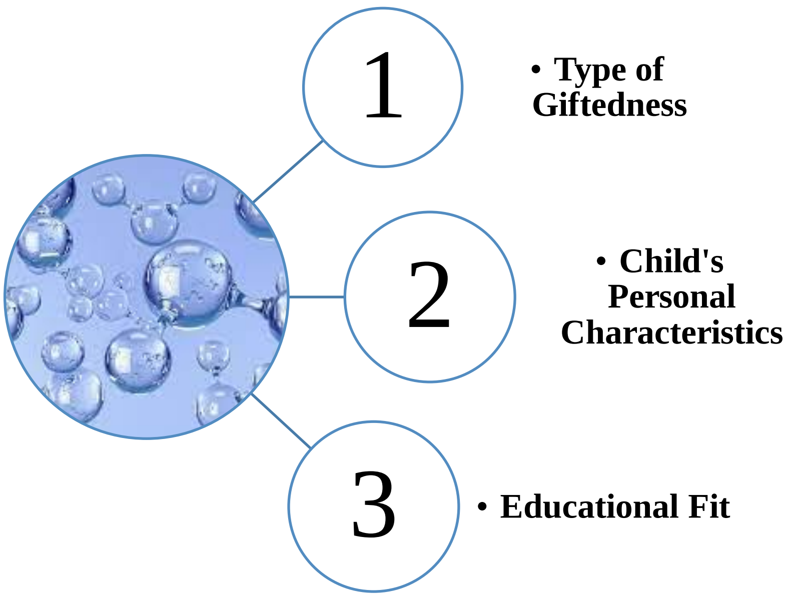
Self-efficacy is also highlighted in a study conducted in Korea, which revealed that a cultural belief can impact educational achievement. This research focused on varied factors that contribute to the high educational achievement of Korean students. The three intersecting components of success in this finding include self-efficacy at the individual level, social support at the relational level, and Confucius values at the cultural level. According to Kim and Park (2007), even though the Korean government spends much less money than the United States on educating children, their students outperform the western students in the areas of math, reading, and sciences. Using indigenous psychology, the study reveals that Koreans believe that education is “self-cultivation,” “knowledge pursued for its own sake,” with the goal of achieving personal, social, and professional success. With this belief, innate abilities do not matter as much as attainment through effort and discipline. Results indicate that parental expectations, support (emotional, not informational), and push, in terms of providing discipline in completing assignments, lead to positive outcomes in the achievement and confidence of the child. In this way, there is no “self-serving bias” because the success of students is directly connected to their efforts, and failure to the lack thereof.

Vulnerabilities of High IQ

Neihart (2010), in a review of the empirical literature, investigated both views of the impact of giftedness on psychological well-being: that giftedness “enhances” resiliency, and in contrast, that giftedness "increases" vulnerability. Empirical and theoretical evidence confirms both. In either case and regardless of the outcomes in gifted children, adolescents, and adults, both positive and negative, there are three factors that work together: the type of giftedness, the educational fit, and the child's personal characteristics. It is the alliance of the three factors that determine the psychological well-being of gifted children (see Figure 25).

Figure 25

Three Essential Factors that Determine the Psychological Well-Being of Gifted Children



Note. This construct is adapted from the work of Neihart, 2010.

In a longitudinal study from infancy to early childhood in France, Vaivre-Douret (2011) reminded us that due to the nature of their cognitive functioning, gifted children are self-critical as early as 3 years of age. However, they have a great sense of humor, generosity towards others, and highly active imaginations that can become a source of anxiety if boundaries are not established and they are not reassured consistently. According to Vaivre-Douret (2011), lack of attention to gifted children at school or at home can lead to behavioral and psychosomatic disorders such as intellectual inhibition, reluctance to meet challenges, mental suffering, and the inability to find fulfillment. In terms of vulnerabilities, boys tend to be more affected than girls.

Eren et al. (2018) conducted a study with participating students ages 9-18 examining the quality of life of gifted children in Turkey. This thorough study used several instruments to explore the quality of life in the areas of social, emotional, and family functionality of gifted children as compared to children of normal IQ. The comparison displayed gifted children as more inattentive with low social functionality and worse perception of the status of their physical health. Gifted boys were more likely to show depressive symptoms than girls in the same group. The data in this study speaks to the likelihood of gifted children being at risk in the areas of mental health and therefore conveys the importance of early identification, providing appropriate education, counseling (by trained professionals) to support their emotional needs, and providing parents, as well as their teachers, with appropriate resources.

When identifying gifted children, multi-dimensional assessments that include the levels of self-regulation and motivation are necessary in addition to intelligence tests (Calero et al., 2007). Efficiency in self-regulation relates to working memory and the orientation of action such as self-motivation where high concentration is demonstrated under high demand. This view speaks to the importance of higher-level content in order to increase high IQ’s engagement and motivational levels. The authors suggested using the SRTC (Self-regulation and concentration test for children) in individuals for both clinical and descriptive purposes.

Sternberg (as cited by Tzuriel et al., 2011) defined intelligence as “the balanced system of abilities” allowing individuals to adapt, construct, and choose environments that afford accomplishing one’s goals in their culture and society. In this study, 145 third grade participating students were divided into four groups: gifted, outstanding high, outstanding low, and typical.

They took a battery of emotional-motivational tests, two measures of cognitive modifiability, and Rey's complex figure tests. The results indicated the "outstanding high group" was higher than the "gifted group" on emotional-motivational factors and cognitive behavioral characteristics. In fact, the gifted students did not demonstrate high scores on the emotional-motivational factors as compared to the other groups. The results indicate that giftedness is not just analytical and verbal precocity and that there are other dimensions such as cognitive modifiability, personality, emotional, and behavioral factors that play important roles in shaping gifted individuals. Therefore, professional development and best practices in teaching are crucial in the development of a supportive educational system for gifted students. Developing interventions that address emotional-motivational factors as well as academic and behavioral factors are of paramount importance.

Upon examining different educational models for the gifted, Subotnik et al. (2011) proposed a comprehensive model that keeps with the following principles: abilities matter, domains of talent vary in each child's developmental trajectories, opportunities can be provided and taken, psychosocial variables are the determining factors, and "eminence" is viewed as the aspired gifted education, while focusing on the central variables of opportunity and motivation.

Gifted children or children with high intellectual capacity demonstrate "overexcitabilities." Karpinski et al.'s (2018) investigation explored the difficulties that come with high IQ, even though positive potential outcomes are predicted. "Hyper brains'" manifestation of overexcitabilities in different domains causes vulnerabilities or inclinations towards certain psychological and physiological conditions. This in turn heightens sensory and inflammatory response, creating a "hyper body." Most illnesses are ones that affect the way one thinks and feels, most commonly depression and mood disorder, ASD, ADHD, and immune dysregulation. The “hyper brain” - “hyper body” connection can lead to implications at individual and societal levels. According to this study, the gifted population is at risk, and further research in identification and services is highly encouraged.

There have been debates over whether individuals who are gifted also struggle with mental health disorders. In a comparative meta-analysis that employed an epistemological lens, researchers highlighted some serious challenges in the gifted population by offering results that analyzed comparison rates of affective disorders such as anxiety, depression, bipolar disorder, suicide ideation, and ADHD (Martin et al., 2010). Of note, previous studies advocating for gifted children have lacked strong empirical evidence and cited disparaged or dated evidence in support of their positions, even, in some cases, trying to hide mental health disorders to “normalize” giftedness, a pattern earlier defined as “reification of speculation” (Cross, 1996).

In the nine studies that met the criteria of the meta-analyses research, Martin et al. (2010) found that none of the studies defined giftedness in the same way. Most of the studies used definitions based upon the students’ enrollment in gifted programs that for the most part indicated unspecified criteria to enter the program. Three of the nine had standardized tests as the basis for their definitions, and two of the studies based their identification on the criteria of intelligence and creativity. In summary, the research suggests that participating gifted students either had the same or lower risks for depression, anxiety, and suicide ideation. There were no studies that compared the counts for bipolar disorder and ADHD in comparative studies.

In a comparative study, Lyman and Luthar (2014) conducted research on two academically gifted groups in grades 11 and 12, at two socioeconomic extremes: one from an affluent private school and the other from a low-income, inner-city magnet school. Negative and positive adjustments were studied in the two extreme groups in relation to perfectionism (including parental pressure to be perfect and personal perfectionism). It was found that even though the low socioeconomic magnet school high ability students were under much more pressure and displayed some relative vulnerability, compared to the affluent group they exhibited much less envy and substance use. In high achieving schools, educators and parents must be cognizant that feeding into perfectionism can be unhealthy and can impact youth's emotional well-being. In fact, family wealth seemed to exacerbate the notion of perfectionism and unhealthy self-criticism. This study speaks to the importance of addressing perfectionism in gifted children and providing the necessary interventions at school to support them to overcome this noted vulnerability.

Interventions

Understanding giftedness in children (high IQ children) empowers parents and teachers with the knowledge needed to meet their academic and socio-emotional needs (see Table 1). Constructing appropriate environments with knowledgeable people is crucial to high IQ children's healthy growth and development. This section will delve into some effective strategies for constructing appropriate environments, parenting and teaching, and understanding giftedness in terms of academic and socio-emotional needs.

Overall, research does not demonstrate the need for a higher level of support in the area of mental health among the gifted/talented (Subotnik et al., 2011). However, there is a gap in longitudinal research in this area, including high ability students. High IQ students are happy when they have friends at school and are highly motivated to learn. Higher life satisfaction can be expected with the right interventions, including more frequent "flow" experience in the G/T, AP or advanced classes at the high school level if they are up for the challenge, receiving greater support from classmates, positive attitude toward school (positive emotions and experiences), exciting academic programs and teachers who are nurturing and supportive, a school that believes that creating an appropriately challenging yet emotionally supportive (Subotnik et al., 2011) academic environment is instrumental to achieving academic success and happiness (positive institutions), and parents who are warm, responsive, and emotionally supportive and who promote autonomy (encouraging positive individual traits and character strengths).

The primary misconception is the assumption that high IQ children will succeed no matter where they are because their families are highly educated and live in the upper levels of social strata (Subotnik et al., 2011). But this is not true. High IQ children may or may not have highly educated parents. They can be found in all races, cultures, and socioeconomic sections of society. The world needs creative and innovative individuals from all levels of society, and so the goal of education for the High IQ should be to provide the right supports in helping all students (not just the high IQ) to attain achievement, where in the right environment they are able to reach for "optimal performance and productivity" (Subotnik et al., 2011).

Vaivre-Douret (2011) asserted that paying attention to only the intellectual advanced status would make the child "bulimic" in comparison to their own abilities, such as the case of too much unhealthy praise for the ability and not the achievement or overemphasizing the talent over all the other aspects of a child. The imbalance between the cognitive and emotional aspects observed in the high IQ developmental trajectories can be detrimental to their emotional well-being. Lack of attention to the socio-emotional needs of these children can lead to major emotional issues as they get older. Therefore, early support and guidance can help to avoid "narcissistic" withdrawal, "behavioral deviance", and personality problems. Sometimes learning disabilities in high intelligence children can be masked by their high abilities. It takes careful observation and professional assessment to ensure there are no hidden learning disabilities. It is important to include emotional-motivational factors in enrichment programs for gifted children. Addressing the socio-emotional aspect of gifted children is significant and requires intervention.

Subotnik et al. (2011) recognized the variables associated with high achievement to include general and domain-specific, creativity, motivation, mindset, task commitment, passion, interest, opportunity, and chance. They described characteristic behaviors such as maladaptive perfectionism, feeling different, heightened sensitivity, and intensity as negative stereotypes that are promoted by advocates of the gifted. Instead of a description of characteristic behaviors, they defined behaviors as outcomes of interaction between the children and their environments. Furthermore, the authors believe that the way in which giftedness is manifested depends upon "psychosocial variables" such as social support, loneliness, social disruption, and social integration, and that cognitive variables in demonstrating talents need to be nurtured at every stage of children's development.

Examining gifted students' mental health with the perspective of positive psychology seems quite promising in terms of intervention (Suldo et al., 2018). The perspective of positive psychology includes the three pillars that are identified as they relate to children and gifted education. Positive psychology fosters strength and growth among all individuals (rather than attention only to those who suffer the most). Inspired by the work of Seligman et al. (2018), it is believed that using positive psychology and seeking resources in the child's environment helps to facilitate well-being by focusing on competencies instead of deficits (See Appendix E).

According to Suldo et al. (2018) well-being correlates with internal qualities (positive mindsets: self-confidence and optimism) and social relationships (supportive relationships with family, friends, classmates, teachers, safety/security, and low stress in terms of life changes). The five key domains in a child's life include school, family, friends, living environment, and the self. This research shows that high achieving learners have “superior well-being” compared to peers. To the high IQ, school satisfaction accounted for a great portion of life satisfaction, but interestingly, school satisfaction contributed little to the typical population. Those high IQ children satisfied with school exhibit heightened academic talents and increased intrinsic motivation. Low satisfaction with school had an adverse effect, even hopelessness. It was found that higher levels of grit, in terms of building resilience, were associated with higher level life satisfaction. Lower life satisfaction was associated with maladaptive perfectionism (having unrealistic expectations of themselves to be perfect) and reliance on ineffective strategies (trying to handle problems alone, keeping to oneself). Educators must proactively identify and intervene with students who demonstrate signs of low motivation, unhealthy perfectionism, and lack of resilience and social health. Professional development and awareness in this area is crucial and developing appropriate approaches to intervening is key to gifted and talented children’s healthy emotional growth.

Table 1

Common Characteristic Domains of High IQ Students

COGNITIVE Processing information to synthesize, conceptualize, and recognize perceived information	**EMOTIONAL** Feelings, emotions, and emotional regulation. This involves individual perception and internalization (intra-brain & inter-brain synchrony)	**BEHAVIORAL** How individuals express and conduct themselves toward others based on their own life experiences
Exhibit notable awareness, deep and genuine curiosity, and longer attention span than most.	Exhibit hypersensitivity to the environment (auditory, visual, touch, gustatory or taste, olfactory or smell).	Difficulty with food, smells, and clothing. Hypersensitivity can lead to demonstration of talent in the arts.
Learn rather quickly, demonstrate remarkable memory, reasoning, and critical thinking.	Exhibit overexcitabilities as a result of hypersensitivity to the environment and/or internalization.	Super energetic when excited, exuberant and animated. “Hyper Brain - Hyper Body”
Exhibit distinct precocity in the verbal, math, or pictorial/abstract thinking domain (not necessarily seen in all three domains).	May exhibit emotional intensity in expressing happiness, joy, sadness, anger, and pain.	May demonstrate somatization- feeling physical pain due to emotional internalization. This can at times be excessive.
Self- directed, autonomous learners in approaching topics of interest.	May exhibit heightened sensitivity and inflammatory response as a result.	Deeply empathetic or deeply angry and sad when lonely or misunderstood.
Abstract and creative thinkers.	Exhibit intuition.	Notable sense of humor.

Note. The information for this table was organized both from my teaching experience with High IQ students and from the work of Guenole et al., 2013 & 2015; Karpinski et al., 2018; Vaivre-Douret, 2011.

In order to provide appropriate services to high IQ students, objectivity in conducting empirical research is necessary, and in that, larger sample sizes should be included in future meta-analytical investigations (Martin et al., 2009). Instead of focusing on one general definition or an array of definitions of giftedness, Martin et al. (2009) highly recommends shifting the focus to specific talents, aptitudes, skills, and capabilities of the high IQ. With this shift in focus, researchers can then plan to identify patterns in the relationship between the aspects and the types of giftedness as single entities and study how they merge with mental health issues. This way of thinking about giftedness will allow for the necessary empirical research and push the field forward in constructing proper programs and appropriate policies for high IQ students, as well as offering resources for professionals and parents who interact with them.

Anxiety in Children Viewed with a Neurological and Psychological Lens

Why do so many children struggle with anxiety? What are the patterns of anxiety disorder associated with high IQ students? How can insights from neuroscience and psychology illuminate our understanding and help us to develop prevention strategies and apply appropriate interventions? This section studies issues relating to students who demonstrate signs of anxiety, as a possible outcome resulting from negative ecosystems.

The case of anxiety in children is likely the most recently talked about topic amongst educators, parents and other professionals who work with children. According to the CDC (Center for Disease Control, n.d.) while fears and worries are components of a child's typical development and growth, persistence and extreme forms of fear can lead to anxiety. In the United States, between 2016-2019, approximately 9.4 % of children between the ages of 3-17 were diagnosed with anxiety (CDC, n.d.). Longitudinal studies indicate that anxiety in children predicts other psychiatric disorders later in adulthood. Left untreated, the symptoms of anxiety in children can become chronic and persistent (Wehry et al., 2015). There are many interactions in the structure of the brain and behavior in the development of children that determine the type and level of anxiety within certain developmental trajectories of a child's life.

Anxiety in Children

Childhood anxiety is among the most common types of childhood psychiatric disorders. While it causes impairment and distress in children, anxiety is often neglected by physicians and other providers working with children (Piacentini and Robleck, 2002). Often there is a misunderstanding that anxiety in childhood and adolescence is developmentally typical, short-lived, and painless. Yet, studies indicate that the onset of childhood anxiety is in early childhood and can become more chronic and serious later in adulthood.

Wehry et al. (2015) examined anxiety disorder in children by taking an epistemological approach. They looked at longitudinal trajectories and neurobiological interactions to inform us of the misunderstanding of the significance of the disorder. Fears are responsive reactions to threats that are normal and developmentally appropriate. Phobias, however, are distinguished from fears in that they are more persistent and there is no logic to them. As well, they are often seen outside of the typical developmental stages. For example, it is developmentally typical for a child to be afraid of the dark at the age of 4. However, the fear of darkness persisting at the age of 15 is not developmentally appropriate. Anxiety is not necessarily specific; it can come across as an "apprehension state" without a certain cause. If the negative force prevails and causes so much distress to the point that it interferes with school, friendships, independent activities, and normal family functioning, it is a cause for concern.

Why does anxiety occur? Wehry et al. (2015) believe there are at least a few identified factors at play: neurobiology, heritability, cognitive processing, and parenting styles. They claim that anxious parents often have anxious children due to both heritability factors and environmental factors such as child rearing, family, and social interactions. Anxiety in parents can be expressed as being overprotective of their children. Like Wehry et al., (2015), Bhatia and Goyal (2018) found genetic, environmental factors, and cognitive biases are all elements of anxiety disorder. Peer pressure, family interactions, and history of psychiatric illness and traumatic events can be studied to better understand the manifestation in a child's anxious behavior. By conducting a thorough screening, and rating and assessing functional impairment among youth in the context of developmental range, Bhatia et al. (2018) identified anxiety symptoms that manifested more in older children. They observed that social surroundings or "milieu" that include pressure from peers, social interactions, and family dynamics could have an impact on anxiety.

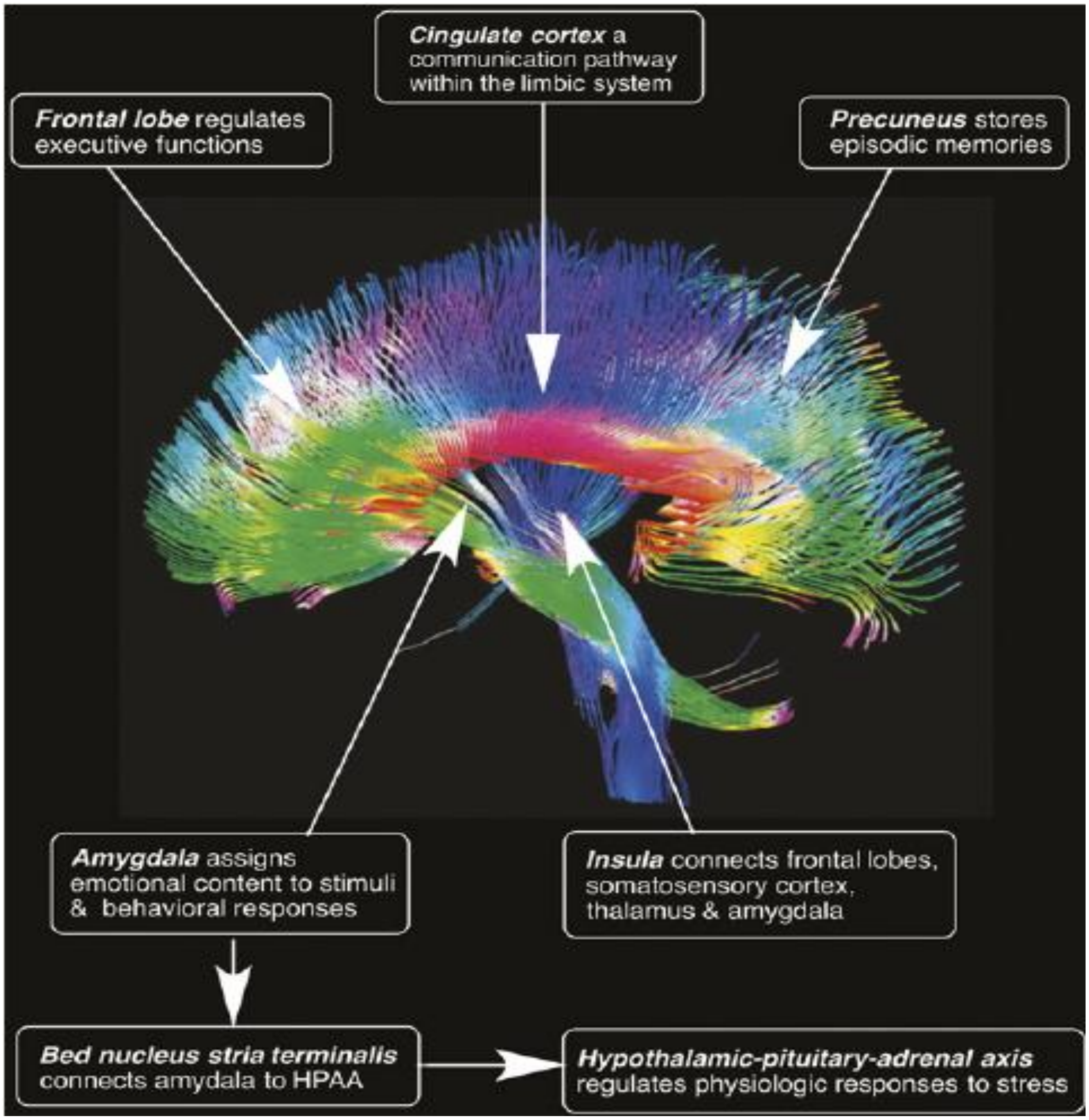
Neurobiology of Anxiety

The neurobiological basis of cognition in relation to anxiety and fear has been investigated in recent years (Hoffman et al., 2012). Advanced technology in the field is unveiling a significant amount of pertinent information by using neuroscience to understand the psychology of clinical disorders and their treatment, revealing the mechanisms. Hoffman et al. (2012) asserted the process of cognition involves thought processes as related to perceiving, recognition, conceiving, and judging. The importance and relevance of stimuli with the processes that correlate with problem solving and executive functions relate to cognitive processes.

Hoffman et al. (2012) used techniques in brain imaging to examine the relationship between emotions such as anxiety and "anxious cognition" (anxiety impairing cognitive performance). They found a connection between abnormal early activity (hypervigilance) in the network of the subcortical area of the brain, which includes the amygdala, hippocampus, insular cortex, and cortical regulatory areas of the anterior cingulate cortex and prefrontal cortex that impact avoidance in response to fear as a strategy (Figure 26). The results of this study led to a cognitive neurobiological information-processing model of fear and anxiety linking the specific structures of the brain to particular stages of information in the processing of perceived fear.

Figure 26

The Regions of the Human Brain That Demonstrate Anxiety Pathways



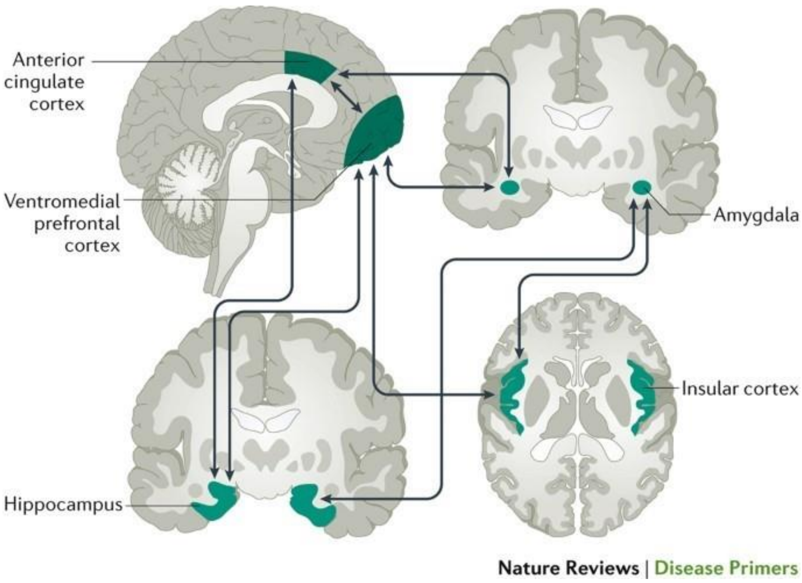
Note. From "Targeting the Modulation of Neural Circuitry for the Treatment of Anxiety Disorders," by D. Farb & M. Ratner, 2014, *Pharmacological Reviews, 66*, p. 1025.

Hoffman et al. (2012) postulated fear as an emotion that has certain properties, which include a "quick, involuntary onset, brief duration, and quick recognition of the stimulus evoking fear" (p. 285). Anxiety is a cognitive association linking basic emotions like fear to events, their meaning, and what kind of response they entail. In anxiety, these associations are less "hardwired" than our basic human emotions like fear, hence making the process of anxiety specific to individuals and their situation. Fear and anxiety are two different entities but what they have in common is their ability to adapt in responding to threats. If these emotions of fear and their responses become intense or excessive in frequency and duration, they can evolve into emotional disorders such as anxiety. There is evidence to support the fact that both fear and anxiety are in a similar family of reactions and present as different anxiety disorders to varying degrees.

According to Wehry et al. (2015), longitudinal studies indicate that anxiety in children predicts other psychiatric disorders later in adulthood. Epidemiologically, the onset of specific anxiety disorders such as agoraphobia, panic disorder, and OCD emerge in adolescence and are more frequently seen in girls. Neurobiological views imply dysfunction in prefrontal-amygdala circuitry (Figure 27). The amygdala is often "overactivated" as seen in fMRI studies (Wehry et al., 2015). The dysfunction in the amygdala goes beyond its activity and its connectivity, including medial prefrontal cortex, anterior cingulate cortex, insula, and cerebellum. The ventrolateral prefrontal cortex (VPFC) regulates amygdala activity, controlling motivation and cognition hyperactivated youth.

Figure 27

Anxiety Disorders



Note. Understanding the neurobiology of anxiety disorders is a work in progress, however, modifications have been identified in the limbic system, and dysfunctions have been noted in the areas of hypothalamic- pituitary-adrenal axis, as well as genetic factors. From "Anxiety Disorders," by M. Craske, et al., *Nature Reviews Disease Primers,* 2017 (https://doi.org/10.1038/nrdp.2017.24)

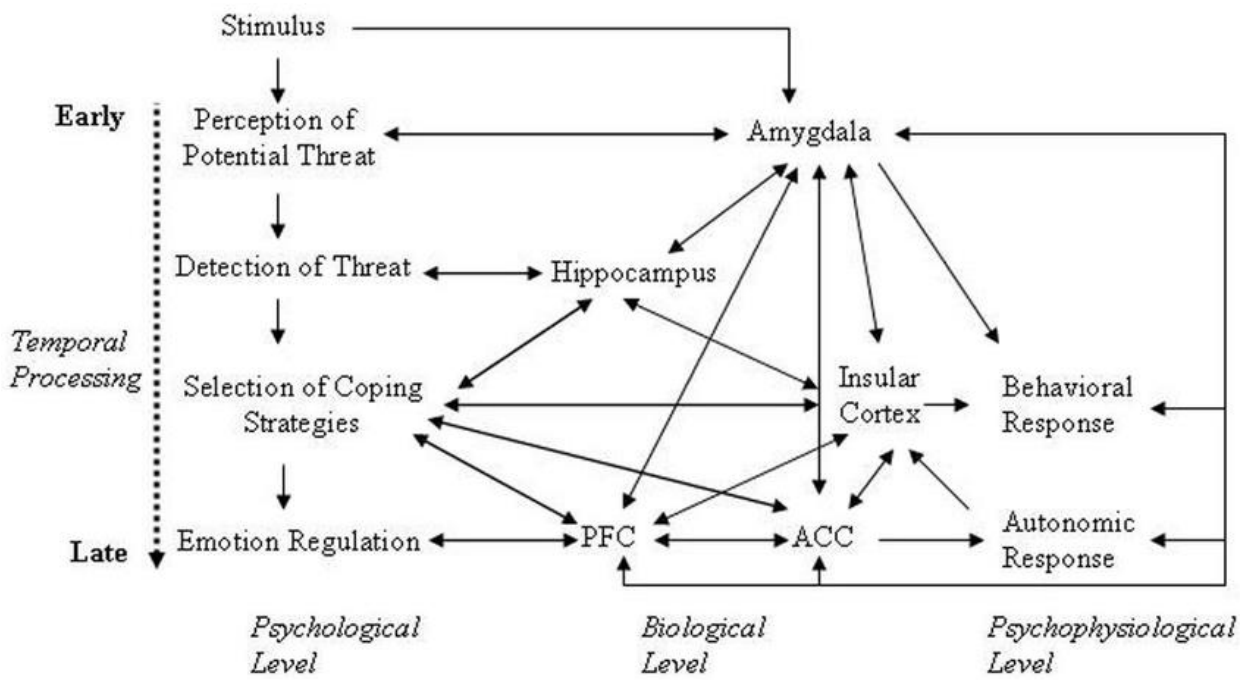
Cognitive Processes of Anxiety

Cognition is the processing of information in order to conceptualize, to know, and to recognize perceived information. Information from the outside world is processed, and then we decide how to use that information to adapt and succeed. The state of anxiety is maladaptive when it creates problems with concentration due to the persisting thoughts about negative events that occur in life. We do not exactly know when anxiety affects cognition. Robinson et al. (2013) identified two types of cognition: "hot cognition" or "emotionally valanced," and "cold cognition" or "affectively neutral" information. Between the two categories a distinction was made within sensory perceptual processes such as early detection (occur very quickly in the subcortical and posterior cortical circuits), attention and control (being able to choose some stimuli over others), memory or retrieval of information, and executive function (integrative and making decisions, a more sophisticated integration of information that is processed cortically).

During the state of anxiety and fear, emotional material and their processing occur in specific brain regions' neural network. The prefrontal cortex (PFC) includes the key brain regions involved in the cognitive regulation of emotions. The lateral PFC involves conscious emotional regulation and executive processes such as conscious avoidance, where the inhibitory factors are weak. Damage to the orbital frontal cortex (OFC) leads to characteristics in impulsivity, emotional outbursts, aggressiveness, shallowness, and argumentativeness (Hoffman et al., 2012). As seen in Figure 28, the path of activation in the brain includes amygdala -> hippocampus -> insular cortex -> prefrontal cortices. In response to stimuli, two cognitive processes are involved: at the early, subconscious level, fast acting, automatic association with the activation of amygdala (thalamo-amygdala-processing of affective representation of sensory cues and cortico-amygdala); at the later stage where slower acting and deliberate processes are detected (slower and more deliberate in the process of complex stimuli). This is the stage where coping strategies apply.

Figure 28

A Cognitive-Neurobiological Information Processing Model of Fear and Anxiety



Note. The cognitive processes of threat are illustrated at psychological, biological, and psychophysiological levels from earlier and later stages. This model shows that anxious cognitive processes and related dimensions of activation of brain regions are closely linked. From "A Cognitive -neurobiological information processing model of fear and anxiety," by Hoffman et al., 2012, *Cognitive Emotion,26* (2) p. 290 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3229257/).

Hypervigilance is a phenomenon that incorporates increased recognition of internal, environmental, and introspective cues in which there is an early emotional reactivity before conscious awareness in the brain. The activities in areas of the brain are associated with sensory perception (e.g., visual cortex), emotional labeling (e.g., amygdala), and interoception (e.g., insula). Hoffman et al. (2012) claimed that facilitated attention, difficulty in disengagement, and attention avoidance are made up of three components of attentional biases that serve as hypervigilance.

In their investigation, Robinson et al. (2013) included healthy volunteers to participate in an experimental model that operationalized anxiety in response to unpredictable, prolonged threats that were not task dependent. The response to shock was considered an adaptive response, not a pathological state. The objectives of the study were to describe the effect of induced anxiety on the process of cognition, and to recognize the commonalities and differences in pathological and trait anxieties. The findings showed that the introduced threat aids sensory-perceptual processing of stimuli, improves the detection of negative information, and impairs performance on tasks that involve emotions, while helping to resolve conflict (adaptive mechanisms to avoid harm). Induced anxiety (Robinson et al. 2013) was distinguished from pathological anxiety-persistent (overly worriedness, and intrusive thoughts about negative future events) which impacts cognition in terms of concentration and working memory. Additionally, anxiety can cause phobias, panic disorders, OCD, PTSD, and high occurrences of depression.

Cognitive bias is a pattern of disparity that is far from the norm in terms of being rational when judging. This is internalization of the person’s perception (subjective) and not from the input received from the outside (objective), that depicts the person’s behavior (Ouimet et al., 2009). Negative cognitive biases form when those who suffer from anxiety and depression react more negatively to stress or to threat-related situations. Negative reactions to stress or threat-related situations manifest in the neurons as “hyper-reactivity” in the brain regions that have to do with recognizing the emotions and generating reactions. These regions involve the amygdala and circuits located in the prefrontal cortex (PFC), the area that plays a key role in controlling cognitive functions. The neurotransmitter dopamine in the area of Prefrontal Cortex (PFC) regulates cognitive control, hence affecting attention, controlling impulsive behaviors, and modulating cognitive flexibility (Hoffman, et al. 2012). Alloy and Riskind's (2008) research formulated a model that shows the differences in how a subject's "associative and rule-based processing" impacts their direction in terms of engagement or lack thereof, avoiding the "threat-relevant" stimulant, and the perception of negative bias in people with anxiety (Figure 26 and Figure 27). These models can serve as a helpful construct for future intervention and further research. In this study, cognitive and social psychology merged to explain how attention and interpretation biases exhibit in anxiety disorder.

According to Beck (as cited in Alloy and Riskind, 2008), individuals form maladjustments or false schemata during their childhood years. The schemata are internalizations that emerge from experiences encountered in the past, present, and anticipated in the future. They impose false, subjective meanings, and therefore influence how individuals process information cognitively. As a result of maladaptive schemata and false internalized interpretations, stressful events make individuals predisposed to emotional disorders. Upon the construction of this type of false cognitive internalization, some "mental processes" begin to culminate resulting in anxiety and depression. This model (Figure 29 and Figure 30) assumes there is a chain of events that lead to vulnerabilities, which then develop and transform into emotional issues or disorders. The chain of events goes back to the individual's childhood years and relationships such as attachments and childhood traumas that construct a person's cognitive processes (attention, memory, imagery, ideation, and automatic thoughts).

Figure 29

Proximal Cognitive Processes Co-occurrent With Specific Episodes of Problems

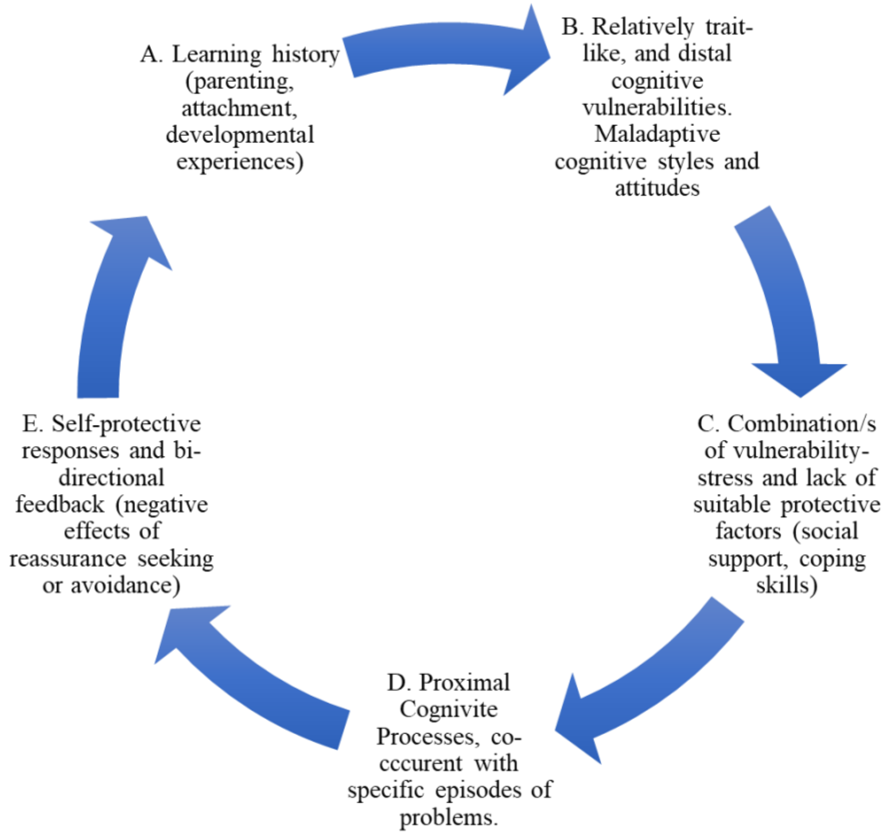


Figure 30

Proximal Cognitive Processes Co-occurrent With Specific Episodes of Problems

Note. These figures demonstrate the construction of schemata. Adapted from information presented in the Theoretical Framework for Cognitive Vulnerability from *Cognitive Vulnerability to Emotional Disorders*, by L. B. Alloy & J. H. Riskind, 2008, Routledge.

The process of cognitive processes is quite complex, and the state of anxiety or anxious thoughts can be maladaptive to the process of learning. The regions of the brain and neural networks that are involved during the cognitive process of anxiety have been identified, including the PFC (Prefrontal Cortex), the area where executive processes and conscious emotions are modulated (Hoffman et al., 2012). Once again, cognitive biases are formed when there is a pattern of disparity, leading to irrational behaviors (Alloy et al., 2008, & Quimet et al., 2009), and the construction of false internalization, the key players in anxiety disorders. The chain of events has been traced back to childhood and the relationships that were experienced during that period (Alloy & Riskind, 2008). This information is significant and serves as a key to understanding why learning cannot occur when children experience anxiety. Furthermore, it explains some of the reasons for irrational behaviors displayed in the classroom.

Anxiety in High IQ Children

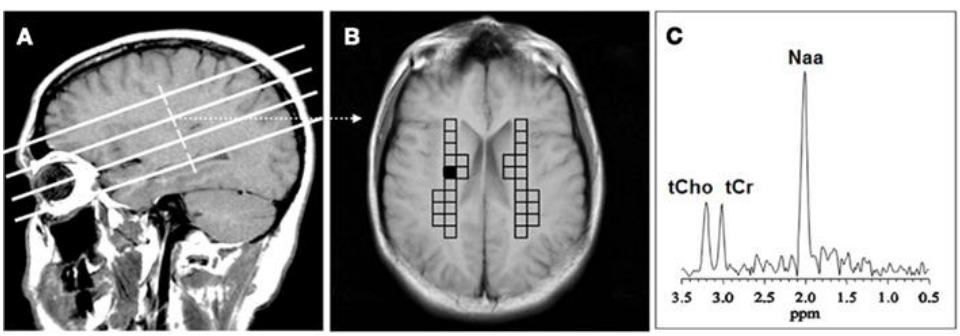
The relationship among generalized anxiety, worry, intelligence, and subcortical white matter metabolism was studied by Coplan et al. (2012). In general, white matter is composed of tracts of myelinated axons that facilitate neural processing through axonal gap junctions, through which channels that connect cells regulate the exchange of ions, affecting physiological processes in the body systems. The participants in this study included patients with generalized anxiety disorder (GAD) and healthy volunteers. It is noted the difference between a non-anxious person and an anxious person is that the non-anxious person can assess that a threat is exceedingly rare and carry on, whereas the anxious person does not abandon the possibility of danger and may adopt avoidance behavioral patterns. The instruments used in this investigation included Penn State Worry questionnaire, WISC assessment, and Proton Magnetic Resonance Spectroscopic imaging (H-MRSI), to measure the subcortical white matter metabolism of choline

(CHO) and other compounds (Figure 31). In comparison to the healthy volunteers who participated in the study, researchers found that patients with Generalized Anxiety Disorder displayed higher IQ's and lower metabolite concentrations in CHO in the subcortical white matter. Combined data of the participants revealed that relatively low CHO predicted relatively higher IQ and worry scores (Coplan et al., 2012).

The relationship between intelligence and anxiety was positive in Generalized Anxiety Disorder (GAD), and inversely apparent in the healthy volunteers (Figure 32). The results suggest that both worry, and intelligence have a shared characteristic of depletion of metabolic substrate in the subcortical white matter, and the evolution of intelligence may have been parallel to worry in humans (Coplan et al., 2012).

Figure 31

MRI Measuring Subcortical White Matter Metabolism

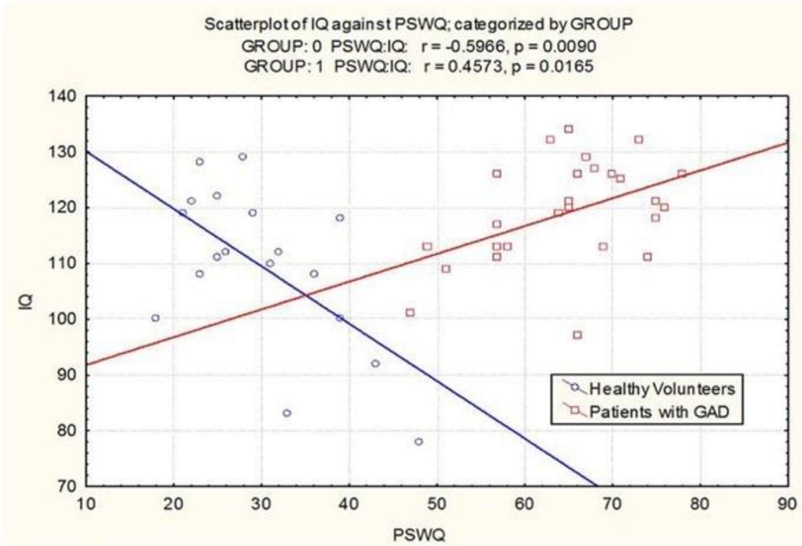


Note. MRI indicates the location of the four brain sections that were investigated in the study. NAA, N-acetyl-aspartate; tCho, total choline containing compounds; tcr, total creatine + phosphocreatine. (A) MRI indicating the location of the four brain sections investigated in the study, (B) Coronal view from the second section (C) Magnetic Resonance Spectrum from the shaded CSO voxel in the grid. From "The Relationship Between Intelligence and Anxiety: An

Association with Subcortical White Matter Metabolism" by J. D. Coplan et al., 2012, Frontiers in Evolutionary Neuroscience, 3, Article 8, p. 3 (https://doi.org/10.3389/fnevo.2011.00008).

Figure 32

Scatterplot of IQ Versus Worry in Patients with GAD and Healthy Volunteers. Group 0= Healthy Volunteers, Group 1= GAD Patients



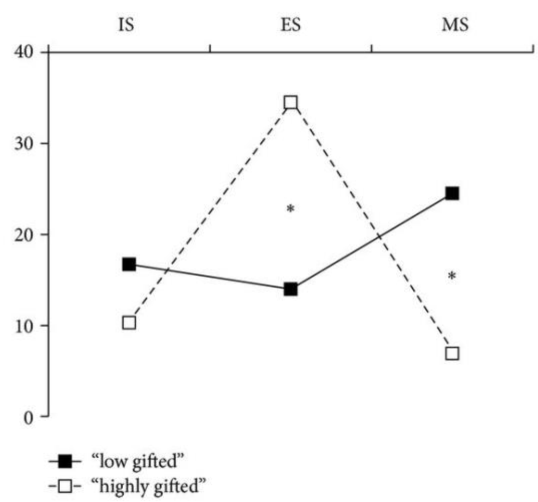
Note. From "The Relationship Between Intelligence and Anxiety: An Association with Subcortical White Matter Metabolism" by J. D. Coplan et al., 2012, *Frontiers in Evolutionary Neuroscience*, *3*, Article 8, p. 5 (https://doi.org/10.3389/fnevo.2011.00008).

Guénolé et al. (2015) conducted an investigation that involved 144 participants of children ages 8-12 in France, identified by Weschler's Intelligence test and behavioral checklist, the authors examined emotional and behavioral issues in the high IQ population of children. They found social adjustment problems to be more prevalent in children with higher IQ (Figure 33). Socioemotional problems tend to increase with higher IQ. This study focused specifically on intellectual giftedness in the verbal domain (SVPS- Significant Verbal Performance Discrepancy).

In another cross-sectional study Guenole et al., found (2013) gifted children with IQ ≥130 and higher were often referred to child psychiatrists for socio-emotional issues and academic underachievement. There was more susceptibility to be “behaviorally impaired,” and to display signs of “developmental asynchrony.” Lack of balance between the cognitive and emotional domain was noted in both internalized and externalized behaviors. Developmental asynchrony is defined as “a problematic pattern of heterogeneities between cognitive, emotional, and psychomotor levels”.

Figure 33

Proportions (%) of Low-Gifted and High-Gifted Children Exceeding Norms



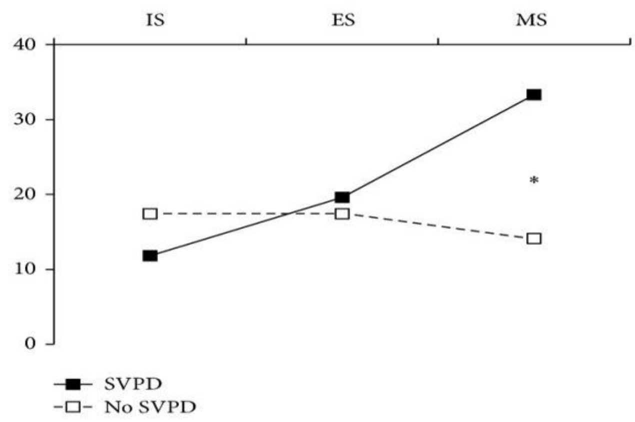
Note. Proportions (%) of “low gifted” and “highly gifted” children whose scores exceeded norms on “Internalized problems,” “externalized problems,” or both. *. IS: internalized syndrome; ES: externalized syndrome; MS: mixed syndrome. From “Behavioral Profiles of Clinically Referred Children with Intellectual Giftedness” by F. Guénolé et al., 2013, *BioMed Research International*, Article 540153, p. 4 (https://www.hindawi.com/journals/bmri/2013/540153/).

Guénolé et al. (2013 & 2015) found that SVPS (significant verbal-performance

Discrepancy) ratings correlate with social and school maladjustment (Figure 34). In other words, children who demonstrated school and social adjustment issues demonstrated higher SVPS ratings. Verbal prominence in children with intellectual giftedness demonstrated more serious emotional symptoms. $1/4^{th}$ of gifted children, SVPD demonstrated dysregulation in emotional and behavioral domains. The authors posit SVPD as a “well established indicator” of imbalance in the cognitive domain. The two findings are compelling to this review because they inform our understanding of small structural differences which can lead to major functional illustrations of behavior. These behaviors are often ignored, misunderstood, misdiagnosed, and therefore mistreated. Gifted children with SVPD indicated lower levels of social preoccupation (where they didn’t engage with peers), exhibiting through internalizing symptoms and social maladjustment as measured by SVPS ratings. This can be observed in behaviors such as withdrawal from peers during recess and reading alone. In the study 20.6% exhibited a high amount of trait anxiety (anxiety level as a personal characteristic versus state anxiety referring to an event) and emotional dysregulation, manifested in difficulty to regulate emotions as expected for their age. Attentional, working memory, and executive resources have been found to be lower in disability.

Figure 34

Proportions (%) of Gifted Children With and Without SPVD



Note. Proportions (%) of gifted children with and without a significant verbal-performance discrepancy (SVPD) whose scores exceeded norms on “internalized problems,” “externalized problems,” or both. *IS: internalized syndrome; ES: externalized syndrome; MS: mixed syndrome. From “Behavioral Profiles of Clinically Referred Children with Intellectual Giftedness” by F. Guénolé et al., 2013, *BioMed Research International,* Article 540153, p. (https://www.hindawi.com/journals/bmri/2013/540153/).

In a comparative study in gifted children, conducted in France, Tordjman et al. (2018) found that 40.5% of the gifted population of 611 children ages 6-16, dealt with anxiety disorders significantly associated with high verbal potential. High verbally gifted children can elicit and/or reinforce anxiety-producing representations and the disorders may lead to defensive over investment of verbal language. This is apparent largely due to their verbal precocity and verbal overexcitability (Dabrowski, as cited in Schlappy, 2019) in the verbal domain.

Benony et al. (2007) questioned whether there is a connection between self-esteem and psychopathological symptoms in children. The study included 58 students that were divided into two groups of gifted and typical adolescents, ages 9-13. Gifted students (IQ ≥ 130 per WISC III) exhibited significantly lower scores than the control group in the area of self-esteem, and their depression scores were higher in this group. The correlation in the investigation indicated that the lower general and academic self-esteem, the higher the depression, hyperactivity, and total psychopathology in the gifted population.

Johnsen (2004) suggests that characteristics of gifted children may be displayed in positive or negative ways. Anxiety as vulnerability in this group can be exhibited in unhealthy perfectionism that leads to self-criticism, fears from high expectations, the inability to self-regulate intense emotions, and social isolation. Unrealistic expectations of high performance by parents and teachers provoke higher levels of anxiety in gifted children.

What are some factors that contribute to vulnerabilities in the high IQ population? Morawska and Sanders (2008) examined parenting styles in the gifted. In their study that included 211 parents who met the criteria, it was noted that impractical parental and "teacher expectations such as high levels of praise and too much parental involvement" exacerbated the elevated levels of emotional symptoms and peer issues. The factors that contribute to vulnerabilities in G/T result from asynchronous development and false expectations such as high levels of praise and too much parental involvement, difficulty with peers and misalignment with the learning environment. Morawska and Sanders (2008) also found that both behavioral and emotional difficulties, specifically the confidence levels of gifted children, were "best predicted" by factors in parenting. Parental reports indicated that parents were less likely to be permissive. More authoritarian parenting styles that were characterized by intense reactions to any problems, as well as frequent lecturing were highlighted in the research as being predictive of emotional difficulties (the data from this study noted 27.6% highly vocal parents, and over reactivity of

41.6%). Parents who expressed higher self-confidence reported less detrimental child behavior and emotional challenges.

These investigations remind us of the increased potential risk for affective disorders and mental health leading to a lower quality of life in high IQ children. As well, sometimes high potentialities mask learning disabilities (Eren et al., 2018; Karpinski et al., 2018; Vaivre-Douret, 2011). Given the broad research in this section, it is crucial to educate teachers and parents. These insights will prepare and equip them with the knowledge necessary in developing the right supports, programs, and interventions for high IQ children.

Interventions for Anxiety in High IQ

Providing appropriate interventions for gifted and talented children is of paramount importance. Appropriate interventions include valid and reliable mediation to help support the vulnerabilities of the high IQ (gifted and talented population), embrace their affordances, and help them to thrive as functional citizens of communities who can make profound contributions toward the betterment of society. This needs to be consistently acknowledged as they are intellectually, creatively, and emotionally capable.

When identifying anxiety in children, an objective assessment that pays close attention to the developmental, cognitive, socioemotional, and biological factors is necessary. Furthermore, multiple sources (parent, teacher, child) and multimethod data (rating, scale, interviews, observational) must be used to pinpoint the disorder present, identify its severity, and finding ways to provide the necessary intervention (Piacentini and Roblek, 2002).

Benony et al. (2007) hypothesized that experienced difficulties in gifted children stem from specific characteristics (at least in part) of their internal and dyssynchronism (imbalance between physiological and mental/psychological aspects). Due to this factor, they may not follow the same developmental trajectories as their age-typical peers. For example, a gifted child may be able to read fluently at the age of 4, at the reading level equivalent to that of a 10 –year old but have the fine motor skills of a 3-year-old, and temper tantrums of a 2-year-old. This leads to a difficult school life resulting in the observed academic self-esteem issues, manifesting in scholastic difficulties and academic failure (Torjman et al., 2018). The challenges can eventually lead to anxiety, depression, hyperactivity, and other disorders that impact schoolwork.

One way to combat anxiety is teaching to replace automatic responses to emotional stimuli with controlled responses such as reducing behavior avoidance, altering automatic thoughts, biases, and distortions provides a powerful treatment method called Cognitive Behavioral Therapy or CBT (Appendix E). Through their cognitive-neurobiological information processing model, Hoffman et al. (2012) asserted that cognition involves thought processes as it relates to perceiving, recognizing, conceiving, and judging the importance and relevance of stimuli with the processes that correlate with problem solving, and executive functions before building plans for execution. The emotion of fear is that of a quick and useful reaction to threatening situations. Based upon Piacentini and Roblek's (2002) investigation, early diagnosis is imperative because anxiety is effectively treated with CBT. Piancentini and Roblek (2002) posit that as interventions, desensitization and exposure to problems and situations can be effective treatments for patients with simple cases of anxiety, but "multicomponent" CBT packages are the treatments of choice for most because this treatment will address the many dimensions of the illness; somatization or somatic: physical complaints, cognitive/biased thinking, behavioral/clinging, crying, and avoidance. Results from this study indicate that CBT can be effective in up to 70% of clinically anxious children. The therapy can be adapted to use at home, school, and other programs. Components of CBT are psychoeducation of child and parents regarding the nature of anxiety, techniques to manage somatic reactions, relaxation, and diaphragmatic breathing, reconstructing thoughts by identifying and challenging anxiety-related thoughts, practicing problem solving, systemic exposure and sensitization (imagined, simulated, in vivo), developing relapse prevention plans, and mindfulness-based psychotherapy (intentional, accepting, non-judgmental attention to thoughts, emotions, and sensations in the moment).

Treatment or intervention is evaluated together with other predictors such as demographic, clinical characteristics, and family factors (Wehry et al., 2015). Further research is needed on generalized anxiety disorder in children since much of what is known about treatment stems from research on adult generalized anxiety disorder. Understanding the different faces of anxiety in gifted children can profoundly change the ways in which we view the environmental milieu such as the classroom and home. This can then inform parenting and classroom management, in which appropriate teaching strategies (that speak to development, neuroscience, and psychology) are developed to meet the needs of this group of children. It is important to keep in mind that scholastic issues can often lead to more serious challenges.

Conclusion

This literature review illustrates how learning is an elaborate process involving many complex neurological measures assembled by cognitive and emotional elements. The human brain is a treasure cove of beauty and truth—with messages of reverence, artistry, and grace—and patterns that, with careful attention, can be decoded. The structure of the human brain lays down the framework for its function, and to understand the operations, one needs to look closely at the construction of this mystical network. Methods such as hyperscanning continue to reveal new truths. There is layer upon layer of complexity in the extraordinary architecture of the brain. The regions are made of brain modules that include visual, attention, frontoparietal control, somatic motor, salience, default, and limbic sections (Bertolero et al., 2019). The layers of brain tissue in the cerebral cortex—including molecular or plexiform, external or granular form, external pyramidal layer, internal granular layer, internal pyramidal layer, multiform or fusiform layer—are composed of a tapestry of cells, and the cells are afforded specific organelles with specialized functions.

Just as quantum particles come together to construct the constituents of atoms, and as atoms combine to construct molecules, the interaction of the molecules in the two major types of brain cells—neurons for communication and glial cells for support and immunity—interact to generate meaning, and the meaning-making is consistently dynamic. The process is remarkably concise and in synch at the neuronal and systemic levels. Each structural connection made in the brain leads to a function that impacts behavior (Klingberg, 2013).

From Maeda (2012) and Klingberg (2013), I learned that it is through the branches of science and mathematics that we attain the means for precision and objectivity, and as an artist, I inherently know that it is through the arts where the message is best portrayed and understood. Artists draw shapes, form, and mass for the sole reason to understand nature's creations. Form allows artists to create a meaningful structure—something that can be an entity by itself, something that is built on a pattern, which repeats itself. According to Hale (1980), the spinning wave line is the basic line of nature. Indeed, the wave lines in the brain shape our thoughts.

As for the artist, the inner depth of an object is revealed when she comes to realize the function behind the elements in art (space, proportion, scale, and depth) revealed by light. And for a keen scientist, wave lines detected in the brain are observed in the curvatures of action potentials and brain oscillations or brain waves. The lines connect to make networks, much like the veins in our arms and our facial nerves that burst into fractal structures.

The investigation I began over 4 years ago only came to fruition upon thinking deeply about the functions of the brain at neuronal and molecular levels. It was at this intersection where I witnessed the hidden beauty that whispered the truth (Plato, 1943) and, quite amazed and in awe, the understanding illuminated my mind. Learning takes place when a neuron is stimulated, and it is that point of stimulation that creates permeability to sodium ions rushing in to depolarize the membrane, generating an action potential or nerve impulse. New action potentials are initiated, propagating a depolarization wave down the axon. Like a wave, the impulse is re-made at each point.

Learning is a beautiful phenomenon – can one measure learning by charting performance? Could it be that in the case of high IQ students, they are misunderstood and feel socially isolated at their schools? Could their repeated socio-emotional challenges lead to psychological stress and anxiety, forming unnecessary negative cognitive biases? Based on the insights from interpersonal neural synchrony, one can deduce that perhaps the problem in educating high IQ students is having “no neural synchrony” or “phase-lagged neural synchrony” (see Figure 13). Might this also be a factor in other types of disparities observed in schools? Perhaps recent interbrain and intrabrain synchrony can begin to provide evidence to increase engagement and social dynamics in the classroom, offering educators and parents new insights into formulating effective preventive methods and interventions when necessary.

In this review of literature, I have collected evidence that illustrates how many elements must come together to support the natural cognitive, social, and emotional learning processes. I view the interaction of students and schools as analogous to that of enzymes and substrates. Enzymes catalyze chemical reactions, and schools as entities could catalyze learning. The active site (or catalytic activity) can be analogous to the developmental trajectory of a child, and finally the right amount of knowledge for each student (or the molecule that binds the active site) is acted upon by the substrate of pedagogy. The function of an enzyme is to increase or speed up a chemical reaction without affecting the equilibrium. Thus, by analogy, schools can facilitate learning, but in order to be effective, they cannot harm the constitution of a child's cognitive and socio-emotional equilibrium.

CHAPTER 3: METHODS

For this research, I chose existing quantitative data that are routinely gathered and used by two urban districts (see Table 2). The urban districts were large and diverse, however the data points provided varied in that District A provided data on 1280 students and District B provided data only on 78 students. The summative data from three categories of tests included the Next Generation Massachusetts Comprehensive Assessment System (MCAS; English Language Arts/ELA, Math, Science Technology Engineering/STE), Cognitive Abilities Test (CogAT; verbal/V, quantitative/Q, nonverbal/NV), English Language proficiency assessments (WIDA ACCESS for English Language Learners/ELLs), demographics, gender, and schools. District A also furnished the number of students on IEPs and 504 plans for learning accommodations and marked students who were economically disadvantaged. Some datasets such as the grade 2 CogAT scores from District B may not be comparable to District A's CogAT due to the age difference since District A administered the CogAT to students in grade 3 while District B administered the CogAt to students in grade 2. Additionally, since the data collected from District B is very limited, it is not used for analysis in question 2.

Below is a summary of the existing quantitative data collected from two large urban districts (as seen in Table 2):

- The Next Generation MCAS scores over 3 years (ELA and Math grades 3 and 5, STE grade 5), School Year (SY) 2016-2017 and SY 2018-2019, respectively.
- The CogAT Abilities-Based Test/CogAT scores in three domains (verbal, quantitative, non-verbal) in School Year (SY) 2016-2017. For the purposes of this study, District A provided CogAT universal data on 1280 grade 3 students while District B provided CogAT universal data *only* on students who were either nominated by teachers or

referred by their parents (a total of 78 students). As a reminder, the CogAT was administered in grade 2 in District B. It is important to note that while District B now offers universal screening for their advanced programming, however, at the time of data collection that was not the case.

- WIDA ACCESS scores for English Language Learner students (ELL) in 4 domains: listening, speaking, reading, writing, and overall. District A provided this data; however, Access ELL data was not used in this study since it was outside of the scope of the guiding questions. A sample analysis can be seen in Appendix G of this research.
- Demographic, economic status data and gender: This study examined score differences in gender subsets and examined score differences in economically disadvantaged students vs the non-economically disadvantaged students.

There are three different types of performance summative assessments in this study: Next Generation Massachusetts Comprehensive Assessment System/MCAS (ELA, Math, STE), the Cognitive Abilities Test/CogAT (verbal, quantitative, and nonverbal batteries), and WIDA ACCESS English Language Learners/ELL (District A). Please refer to Appendix C for more information about the different types of assessments.

The main goal of the study is constructed around questions that can be informed by the knowledge of neuroscience. Demographic data is examined in terms of assessment results and since age percentiles are used in the summative assessments, the study adheres to percentile scores. Obtained scores from different genders (District A) are evaluated to see if there are any observable differences across the variables (MCAS: ELA, Math, STE & CogAT: verbal, quantitative, and nonverbal). The MCAS ELA and Math are summative assessments required by the state and administered annually at schools. In addition to MCAS ELA and Math, grade 5 students take the MCAS STE (Science, Technology, Engineering). The CogAT is administered as a screening tool once and by the sole discretion of the schools within these two districts, to select students who meet the eligibility requirement for academically advanced students or gifted and talented programming. The CogAT contains three batteries (verbal, quantitative, nonverbal) and is administered in three separate sessions.

The furnished data is representative of data commonly used in public schools in the Commonwealth of Massachusetts and similar to schools in other states, therefore a close examination of the selected data would be constructive and informative for the participating districts and other public school systems.

The following sections describe the acquired data and the instruments included in the data and methods used for statistical analysis.

Data

The participants in this study included one cohort of students who were in grade 3 during the 2016-2017 academic year and later in grade 5 during the 2018-2019 academic year. The total number of students provided by District A was 1280 and the total number of students provided by District B was 78, respectively. While information about individual schools was obtained, I did not request data on teachers who taught the perspective grade levels to ensure anonymity.

Table 2

Outline of District Data

Type of Publicly Available Data (Provided by the districts)	District A Attained / Analyzed	District B Attained / Analyzed
Grade 3 ELA and Math MCAS (SY 2016-2017)	N= 1280 / n= 953	N= 78 / 78
Grade 5 ELA, Math, and STE MCAS (SY 2018-2019)	N= 1280 / n= 953	N= 78 / 78
Grade 2 CogAT Form 7 screening in the verbal, quantitative, and nonverbal batteries (SY 2015-2016), available only on students who were nominated and/or referred for testing.	0	N= 78 / 78
Grade 3 CogAT Form 7 universal screening in the verbal, quantitative, and nonverbal batteries (SY 2016-2017)	N= 1280 / n= 953	0
WIDA Access ELL Scores Grade 3 SY 2016-2017	N= 1280 / n= 953	0

Type of Publicly Available Data (Provided by the districts)	District A Attained / Analyzed	District B Attained / Analyzed
WIDA Access ELL Scores Grade 4 SY 2017-2018	N= 1280 / n= 953	0
WIDA Access ELL Scores Grade 5 SY 2018-2019	N= 1280 / n= 953	0
Demographic Data	N= 1280 / n= 953	0
Schools attended	N= 11	N= 6

*District A: N= 953; District B: N=78 (this is the number of students in Districts A and B who had all the scores for this analysis). The shaded cells indicate the data used in this study.

Districts

The description of each site is articulated below,

(a) District A: The city is home to over 100,000 residents, educating over 15,000 students. The class of 2020-2021 indicated the following estimates for race and ethnicity: African American- about 60%, Hispanic- over 18%, White- about 14%, Asian- below 2%, Multi-Race/Non- Hispanic- over 4%, Native Hawaiian/Pacific Islander- below 0.2% (per profiles.doe.ma.edu). About 50% of the residents living in the city speak languages other than English at home. Over half of the district's students in this cohort are reported "economically disadvantaged" and qualified for Federal Financial Assistance, and over 12% of the residents live in poverty. There are a few colleges and universities, youth programs, and training resources (per the city and district's website).

(b) District B- The city is home to over 60,000 residents and over 5000 students. The class of 2020-2021 indicated the following estimates for race and ethnicity: African American- over 9%, Hispanic- over 40%, White- about 40%, Asian- about 5%, Native American- about 0.1%, and Multi-Race/ Non-Hispanic- over 2% (per profiles.doe.mass.edu). Over 30% of residents in this city speak languages other than English at home. About 10% of the residents reported living in poverty. Additionally, this district offers homeless assistance program and resources for immigrant families. There are a few colleges and universities, private schools, and a family school providing literacy programs for the residents (per the district's website).

Both districts offer programs for their academically advanced students in the upper elementary grades (grades 3-5). Similar to students on 504's and IEP's, students identified as academically advanced participate in academically appropriate instruction in settings that support higher academic levels.

Instruments

Next Generation Massachusetts Comprehensive Assessment System, MCAS (ELA, Math, STE)

Refer to Appendix C for the description of the instrument and additional resources related to this instrument.

Cognitive Abilities Test, CogAt (verbal, quantitative, nonverbal)

Refer to Appendix C for the description of the instrument and additional resources related to this instrument.

WIDA ACCESS English Language Learners (ELL)

Once again, WIDA ACCESS ELL scores are not utilized in this data analysis in order to adhere to specific research questions in this examination. However, a sample scatterplot is provided in Appendix G to indicate the relationship between WIDA ACCESS ELL scores and MCAS.

Refer to Appendix C for the descriptions of the instruments and additional resources related to the instruments.

Table 3

Districts A and B Performance Data

Test	2016 (Gr. 2)	2017 (Gr. 3)	2019 (Gr. 5)
MCAS ELA		District A & B	District A & B
MCAS Math		District A & B	District A & B
MCAS STE			District A & B

Test	2016 (Gr. 2)	2017 (Gr. 3)	2019 (Gr. 5)
CogAt Verbal	District B	District A	
CogAt Quantitative	District B	District A	
CogAT Nonverbal	District B	District A	
ACCESS Listening	x	x	x
ACCESS Speaking	x	x	x
ACCESS Reading	x	x	x
ACCESS Writing	x	x	x

*The shaded cells indicate the data used in this study. “x” indicates data used in Appendix G.

Analytical Procedure

Below is a summary of the steps that have been completed for this research,

Data Acquisition

Two large, diverse, urban districts provided data for this study. Data included the 2017 grade 3 MCAS ELA (English Language Arts) and Math, and CogAT verbal, quantitative, and nonverbal batteries; the 2019 grade 5 MCAS ELA, Math, and STE (Science, Technology, Engineering); WIDA ACCESS ELL scores for English Language Learners when applicable. Students who were economically disadvantaged were marked, and gender, ethnicity, and schools were also recorded. The data provided in its entirety was anonymized by the districts to remove any personally identifying information. Unique IDs were assigned to students by the districts in order to be able to track them if further examination is needed. District A provided CogAT universal data on 1280 third grade students while District B provided CogAT universal data *only* on students who were either nominated by teachers or referred by their parents (total of 78 students). District B now offers universal screening for their advanced programming, however, at the time of data collection that was not the case. MCAS scores over 2 academic years (ELA and math grades 3 and 5, science grade 5), SY 2016-2017 and SY 2018-2019, respectively; ACCESS WIDA scores for English Language Learner (ELL) students were collected in 4 domains:

listening, speaking, reading, writing, and overall. For this research District A provided WIDA ACCESS ELL for their district's ELL students (see Table 3).

Data Organization

The data for each district was organized into a table consisting of one student per row. The columns contained the various data from each district which included MCAS scores and MCAS Growth Percentile, CogAT scores, gender, economic status, WIDA ACCESS ELL scores, and schools attended. This table did not include complete data for all students. As a result, not every row was used for analysis- students who were missing scores were removed from the table. For example, District A provided a list of 1280 students but only a large, complete subset of 953 was used for analysis.

Generating Questions

I began by developing questions about the performance data, and how one performance assessment relates to the other, and noted any observable growth trajectories. Some key questions included,

- How do the CogAt and MCAS data correlate?
- How well do the CogAT scores predict MCAS scores? and if so, to what extent?
- What is a better predictor of the growth in achievement: original MCAS score or original CogAT score?
- How much growth can be predicted through MCAS data?
- Is the CogAT data a predictor of the trajectory across the two academic years? What trajectory is observed? Are there increases? If so, in what areas?
    - What does that trajectory look like for high ability students? Is a program or additional enrichment making a difference in terms of performance?

- Environmental factors- grouping students into two subgroups: students who received enrichment and students in the non-enrichment group. Analyze the core functions of enrichment. Is enrichment really making a difference in terms of performance?
- Study the students at the margins and their trajectory. Do the students benefit from having been identified? What kind of growth is observed in their scores? What are the core functions of achievement or the MCAS?

The preliminary questions were then grouped into 3 emerging themes and articulated as guiding questions (see Table 4),

1. **Longitudinal performance:** track students across time to determine the correlation between earlier test scores and later test scores, and growth trajectory.
   (a) What is the relationship between grade 3 and grade 5 MCAS test scores for the same group of students? How do the two districts compare?
   (b) What is the relationship between earlier test scores and growth trajectory observed in the 5th grade MCAS performance?
2. **Examination of the datasets:** conduct analysis of available data to examine the distribution of MCAS and CogAT scores against attributes of gender, economically disadvantaged and anonymized school ID across two districts. Only District A provided gender and economic status; therefore, District B will not be included in the analysis for Questions 2A-2F. Both districts provided school information and are included in Question 2g.

(a) Are there observational similarities or differences between genders with regards to test scores?

(b) What percentage of the students who were identified as either male or female, did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) expectations? What percentage met (M) expectations? What percentage exceeded (E) expectations?

(c) Are there observational similarities or differences between genders with regards to MCAS growth from grade 3 to grade 5?

(d) Are there observational similarities and differences between students identified as economically disadvantaged (EcoDis) and students who were not economically disadvantaged (non-EcoDis)?

(e) What percentage of the students who were identified as economically disadvantaged, did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) the MCAS expectations? What percentage met (M) the MCAS expectations? What percentage exceeded (E) expectations?

(f) Are there similarities or differences observed in the MCAS growth percentile from grade 3 to grade 5 with regards to economic status?

(g) What type of growth percentile is observed in each of the districts' schools?

3. **Neuroscience and Education:** use a neuroscience lens to examine quantitative performance data and non-quantitative attributes data to observe

how the results can inform neuromyth free implications related to the field of education.

(a) Examination of quantitative performance data: What kind of plausible insights from the instruments (Next Generation MCAS and the CogAT) can be reflected in the results?

(b) Given our current knowledge of neuroscience, how can we use a neuroscience-informed practice in the classroom?

Table 4

Guiding Research Questions

Theme	Questions
1. **Longitudinal performance:** track students across time to determine the correlation between earlier test scores and later test scores, and growth trajectory.	(a) What is the relationship between grade 3 and grade 5 MCAS test scores for the same group of students? How do the two districts compare? (b) What is the relationship between earlier test scores and growth trajectory observed in the 5th grade MCAS performance?

Theme	Questions
2. **Examination of the datasets:** conduct analysis of available data to examine the distribution of MCAS and CogAT scores against attributes of gender, economically disadvantaged and anonymized school ID across two districts. Only District A provided gender and economic status; therefore, District B will not be included in the analysis for Questions 2A-2F. Both districts provided school information and are included in Question 2g.	(a) Are there observational similarities or differences between genders with regards to test scores? (b) What percentage of the students who were identified as either male or female, did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) expectations? What percentage met (M) expectations? What percentage exceeded (E) expectations? (c) Are there observational similarities or differences between genders with regards to MCAS growth from grade 3 to grade 5? (d) Are there observational similarities and differences between students identified as economically disadvantaged (EcoDis) and students who were not economically disadvantaged (non-EcoDis)? (e) What percentage of the students who were identified as economically disadvantaged, did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) the MCAS expectations? What percentage met (M) the MCAS expectations? What percentage exceeded (E) expectations? (f) Are there similarities or differences observed in the MCAS growth percentile from grade 3 to grade 5 with regards to economic status? (g) What type of growth percentile is observed in each of the districts' schools?
3. **Neuroscience and Education:** use a neuroscience lens to examine quantitative performance data and non-quantitative attributes data to observe how the results can inform neuromyth free implications related to the field of education.	(a) Examination of quantitative performance data: What kind of plausible insights from the instruments (Next Generation MCAS and the CogAT) can be reflected in the results? (B) Given our current knowledge of neuroscience, how can we use a neuroscience-informed practice in the classroom?

Developing Hypotheses

Hypotheses were developed based on my current knowledge of neuroscience research and related to education in the "neuroscience and education" theme of the guiding questions (Question 3). In this process I consistently reflected on the current neuromyths identified in the field of education.

Datasets

Preliminary data analysis was performed using tools such as Microsoft Access, Microsoft Excel, and Tableau to create visual representations of the data in the form of scatterplots and quantitative analysis using linear regression. These tools allowed for querying of the data, selecting different subsets based on properties, and graphing the results for visualization.

Statistical Analysis and Verification

Data examination and statistical analyses were performed and statistical tools such as linear regression and one-way ANOVA were utilized. Linear regression analysis was primarily used on datasets in accordance with the guiding research questions. Having run multiple regression observations offered powerful methods to identify these relationships while affording the ability to reach reliable interpretations. At the same time, every care was taken to protect the confidentiality of the furnished data. Question 1A includes the result of these regression tests in Table 9 and Table 10.

One-way ANOVA was also utilized to determine whether score differences between groups were statistically significant. Question 2 includes the result of these ANOVA tests in Table 13, Table 15, Table 16, and Table 20.

Examination

The outcome of the data analysis would either support or not support the hypotheses and identify areas in which further research and investigation is needed. The implications of data analysis were examined to see if insights from neuroscience could explain the findings, and if so, the significance of what was revealed in this examination (see Figure 3).

The main goal of the study was constructed around questions that could be informed by the knowledge of neuroscience. In order to understand the development and logic behind the summative assessments, online and available guiding literature was used, and Massachusetts's Department of Elementary and Secondary Education (DESE) was contacted with further questions regarding the Next Generation Massachusetts Comprehensive Assessment System (MCAS).

CHAPTER 4: RESULTS

Scientific Method: Question > Research and gather information > Form hypotheses > Analyze data > Examine results > Discuss findings > Draw conclusions

Question 1

Longitudinal performance: track students across time to determine the correlation between earlier test scores and later test scores, and growth trajectory (Districts A and B). The following table shows the relationships that will be examined.

Table 5

Question 1A Score Related Variables Description

Early Test	Later Dependent Test for Examination
CogAT Verbal (District A- 3rd grade, District B- 2nd grade)	MCAS ELA (3rd Grade), MCAS Math (3rd Grade), MCAS ELA (5th Grade), MCAS Math (5th Grade), MCAS STE (5th Grade)
CogAT Quantitative (District A- 3rd grade, District B- 2nd grade)	MCAS ELA (3rd Grade), MCAS Math (3rd Grade), MCAS ELA (5th Grade), MCAS Math (5th Grade), MCAS STE (5th Grade)
CogAT Nonverbal (District A- 3rd grade, District B- 2nd grade)	MCAS ELA (3rd Grade), MCAS Math (3rd Grade), MCAS ELA (5th Grade), MCAS Math (5th Grade), MCAS STE (5th Grade)
MCAS ELA (3rd Grade)	MCAS ELA (5th Grade), MCAS Math (5th Grade), MCAS STE (5th Grade)
MCAS Math (3rd Grade)	MCAS ELA (5th Grade), MCAS Math (5th Grade), MCAS STE (5th Grade)

Table 6

Question 1B Performance Related Variables Description

Early Test	Later Dependent Test for Examination
CogAT Verbal (District A- 3rd grade, District B- 2nd grade)	MCAS ELA Growth (5th grade), MCAS Math Growth (5th grade)
CogAT Quantitative (District A- 3rd grade, District B- 2nd grade)	MCAS ELA Growth (5th grade), MCAS Math Growth (5th grade)
CogAT Nonverbal (District A- 3rd grade, District B- 2nd grade)	MCAS ELA Growth (5th grade), MCAS Math Growth (5th grade)
MCAS ELA (3rd Grade)	MCAS ELA Growth (5th grade), MCAS Math Growth (5th grade)
MCAS Math (3rd Grade)	MCAS ELA Growth (5th grade), MCAS Math Growth (5th grade)

Question 1A

What is the relationship between grade 3 and grade 5 MCAS test scores for the same groups of students? How do the two districts compare?

Hypothesis

It would seem reasonable to assume if students performed well in an earlier test, they would continue to perform well in the later tests.

While the CogAT is marketed as an abilities-based assessment and MCAS a performance-based assessment, is one more correlated to later scores than the other?

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. The total number of students for this exercise was 953 (n = 953).

District B provided complete data (MCAS and CogAT) for a total of 78 students (N=78). MCAS scores are presented as a scaled score provided by Massachusetts Department of Education (Mass DOE) and range from 440 to 560. Mass DOE categorizes score ranges as follows.

Table 7

Mass DOE MCAS Achievement Levels

Achievement Level	Range
Not Meeting Expectations (NM)	440-469
Partially Meeting Expectations (PM)	470-499
Meeting Expectations (M)	500-529
Exceeding Expectations (E)	530-560

CogAT scores are presented as a percentile, as calculated by CogAT tests, which range from 1 to 99 (see Appendix C).

Examination

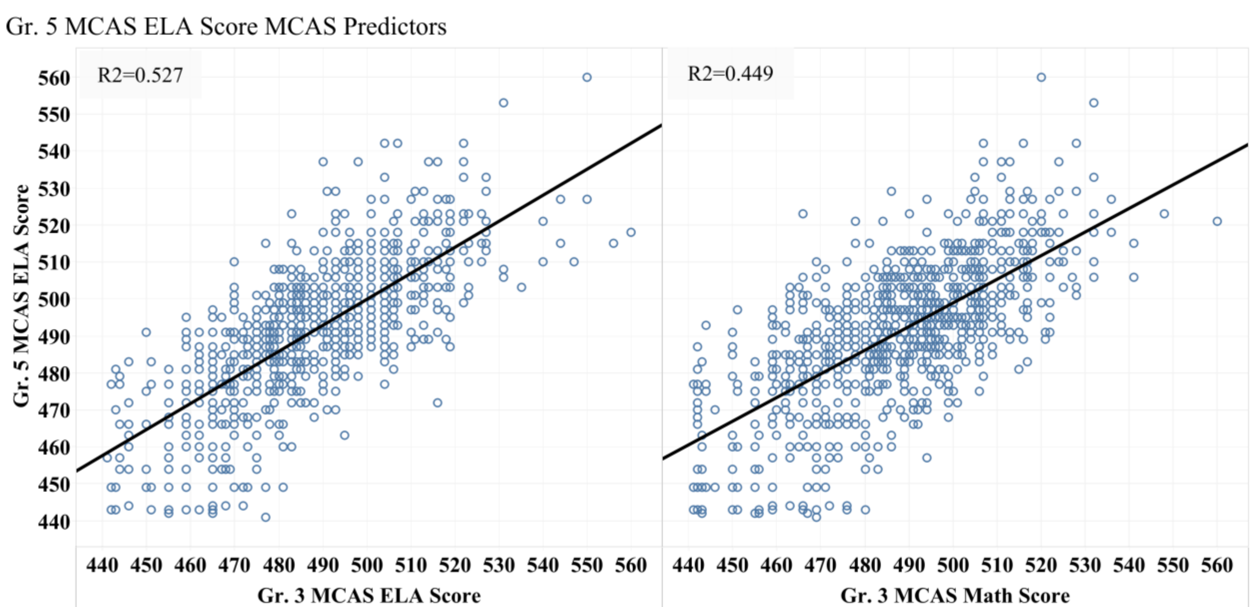
Scatterplots were utilized to produce the first glimpses into the data, illustrating the relationship between 3rd grade MCAS scores and 5th grade scores. Scatterplot is a tool that can easily and quickly illustrate a visual representation of how the data might relate. The scatterplots seen here and in Appendix H show the relationship between the input (earlier test) and output (later test).

Linear regression was used to provide a mathematical and quantitative measure of the relationship between the two scores.

Visual inspection of the following scatterplots exhibits a degree of correlation between the scores, which encourages use of linear regression for further analysis.

Figure 35

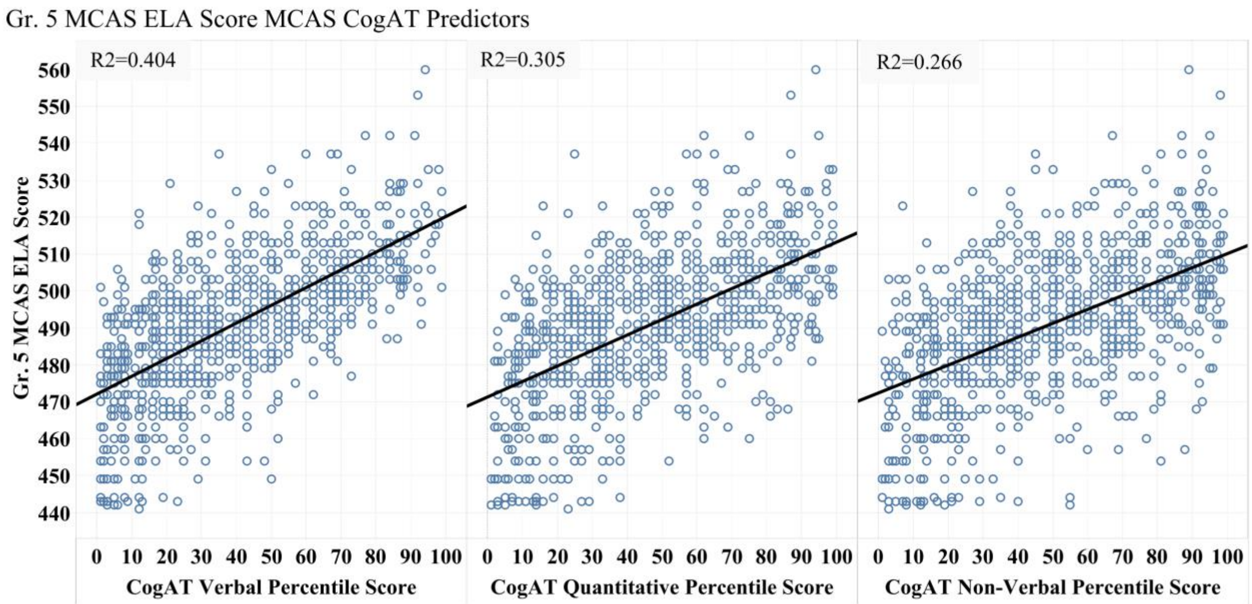
District A Grade 5 MCAS ELA Score vs MCAS Predictors



N = 953

Figure 36

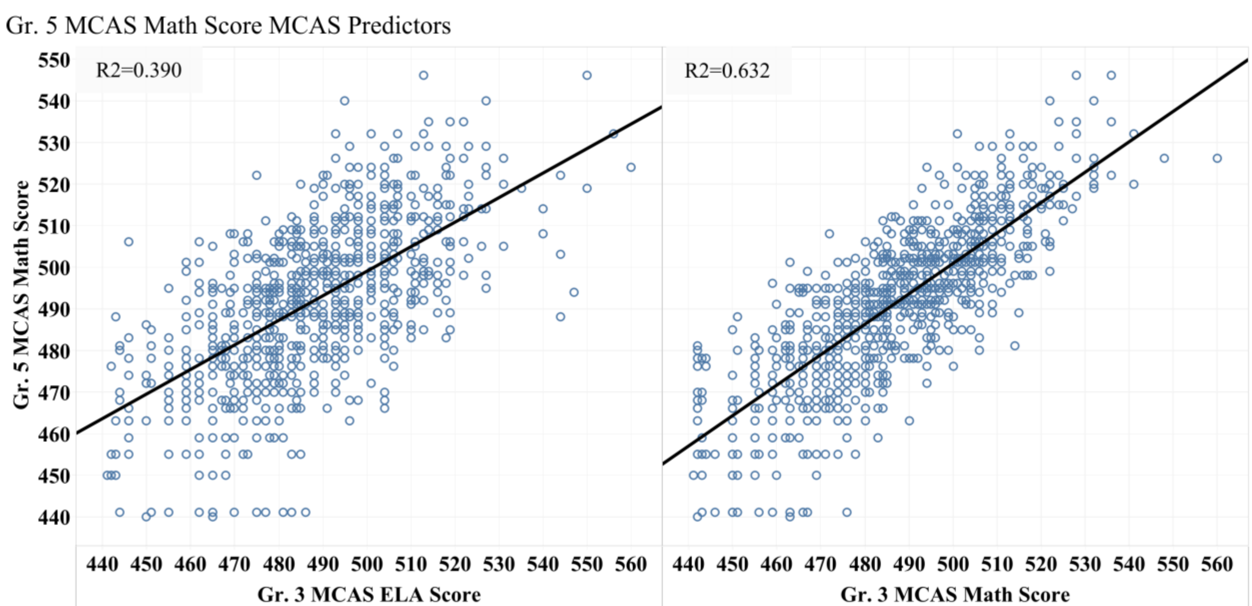
District A Grade 5 MCAS ELA Score vs CogAT Predictors



N = 953

Figure 37

District A Grade 5 MCAS Math Score vs MCAS Predictors



N = 953

Figure 38

District A Grade 5 MCAS Math Score vs CogAT Predictors

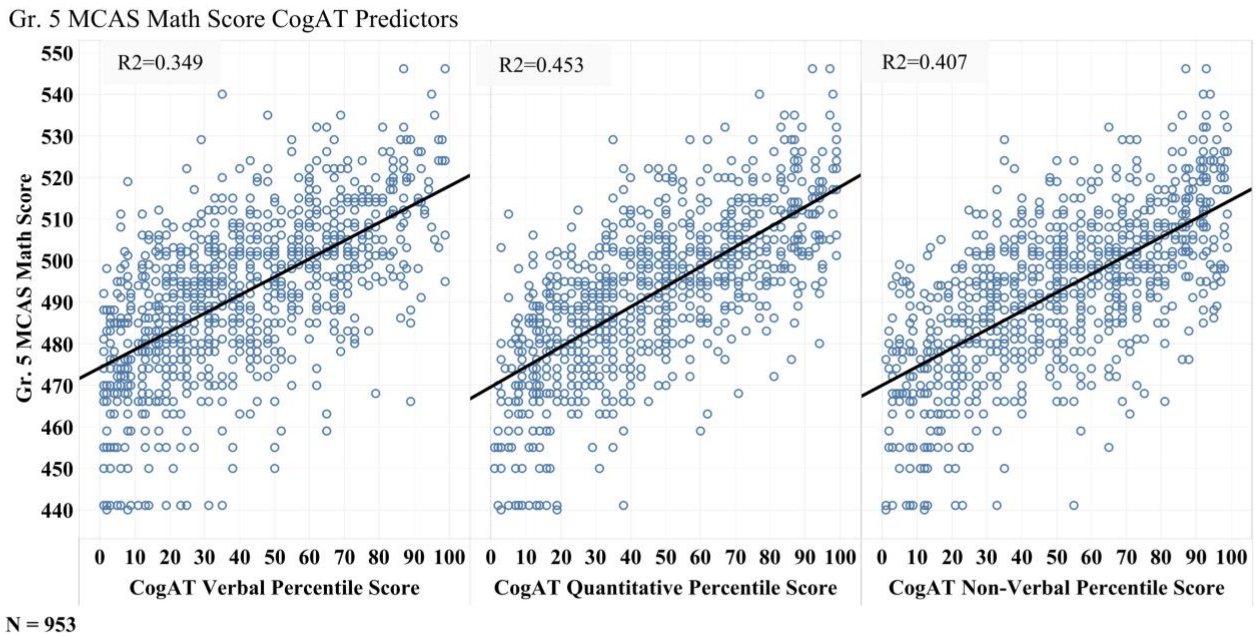


Figure 39

District A Grade 5 MCAS STE Score vs MCAS Predictors

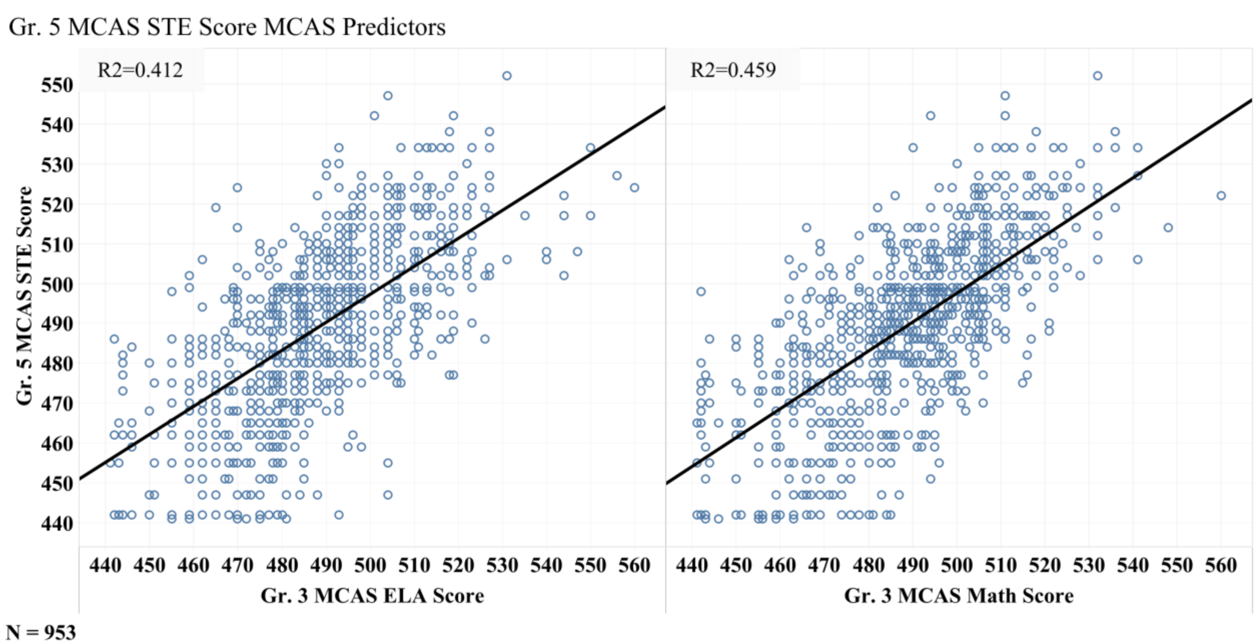


Figure 40

District A Grade 5 MCAS STE Score vs CogAT Predictors

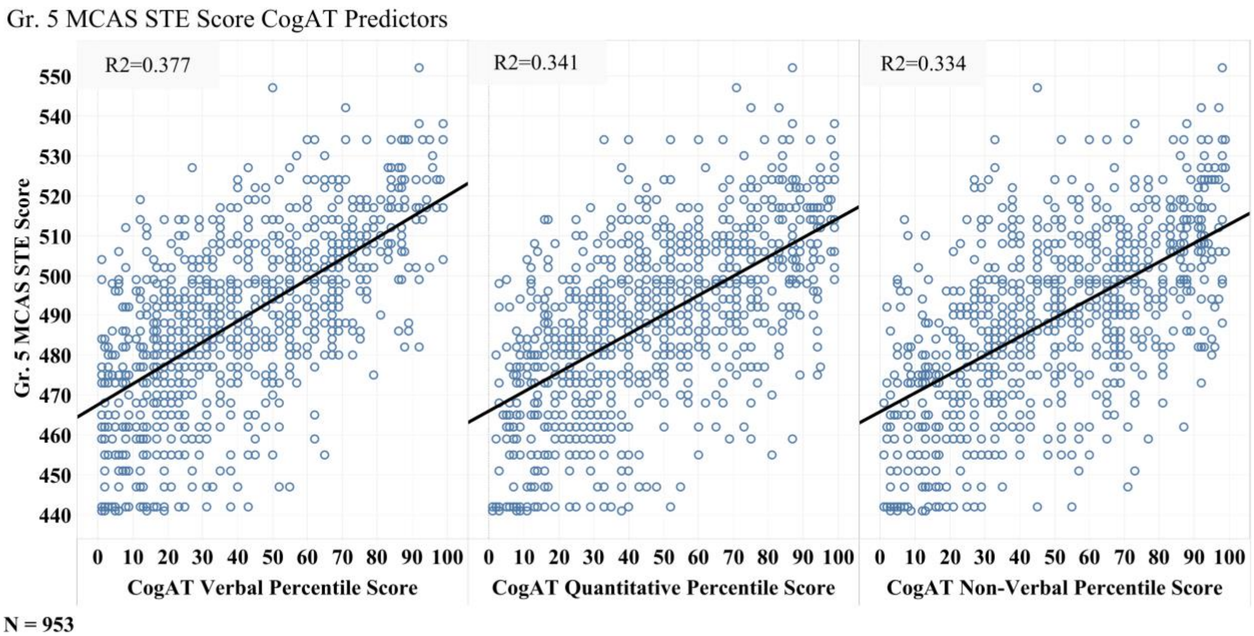


Figure 41

District B Grade 5 MCAS ELA Score vs MCAS Predictors

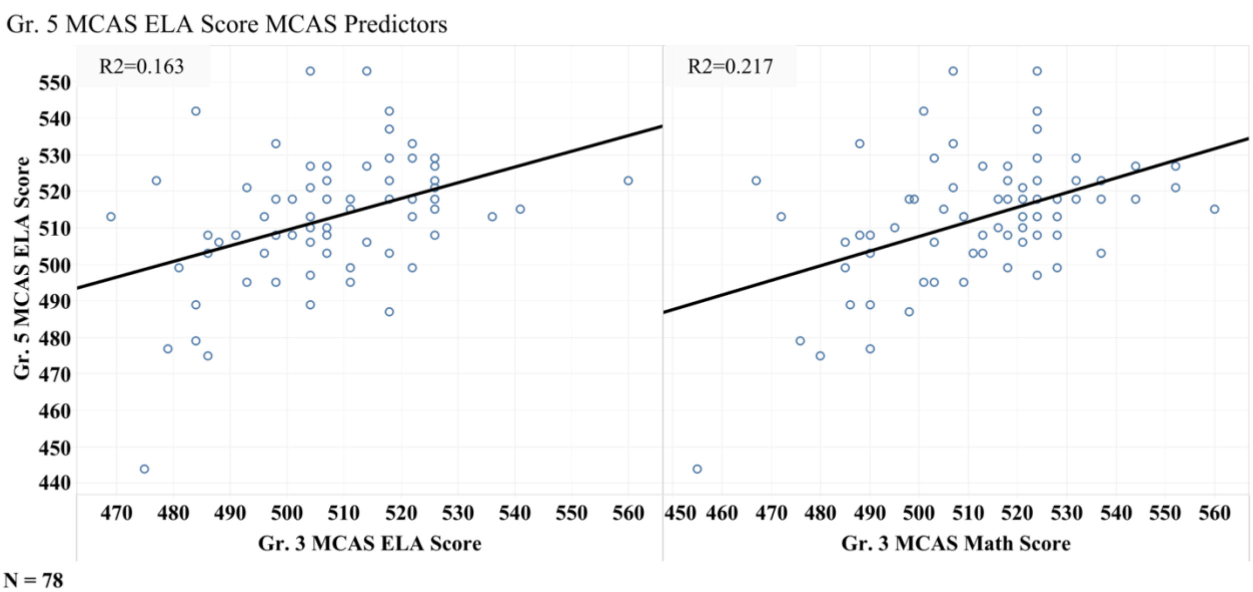


Figure 42

District B Grade 5 MCAS ELA Score vs CogAT Predictors

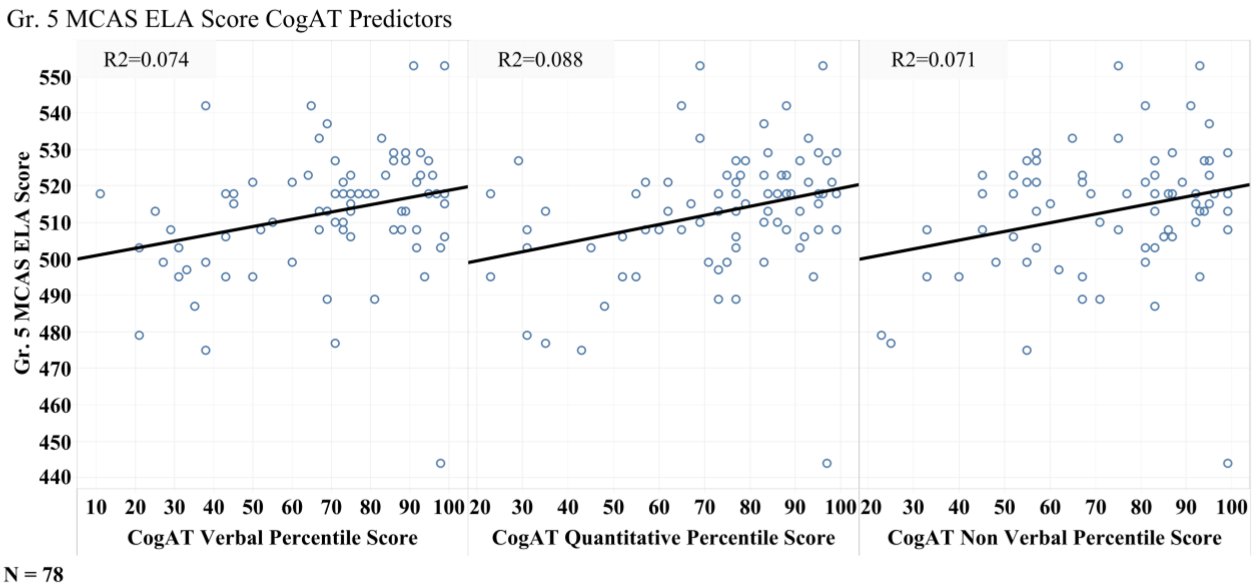


Figure 43

District B Grade 5 MCAS Math Score vs MCAS Predictors

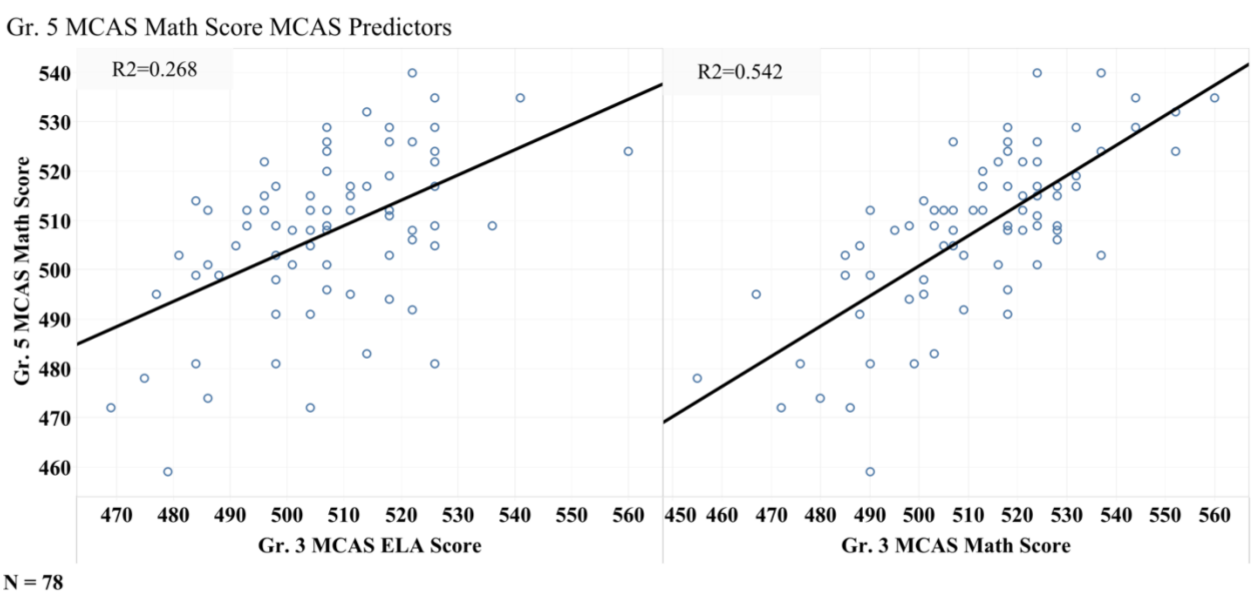
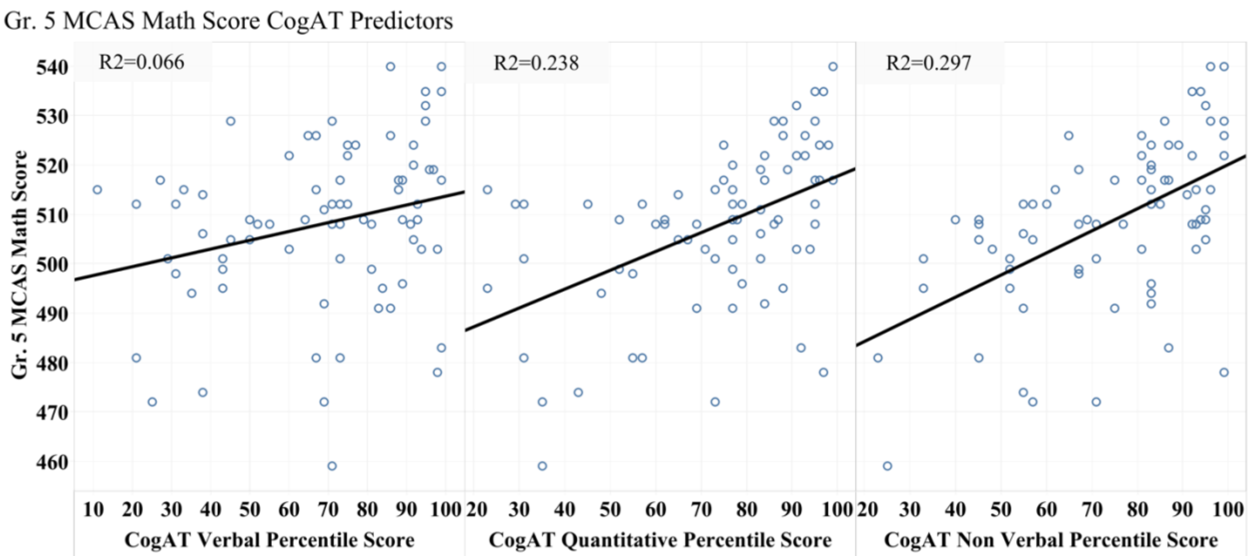


Figure 44

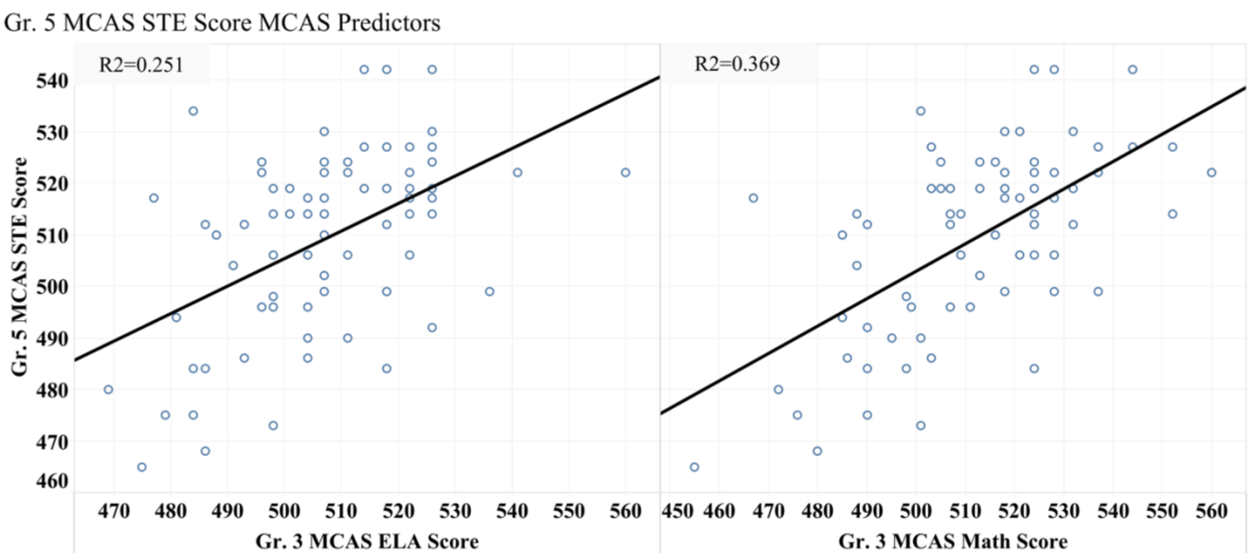
District B Grade 5 MCAS Math Score vs CogAT Predictors



N = 78

Figure 45

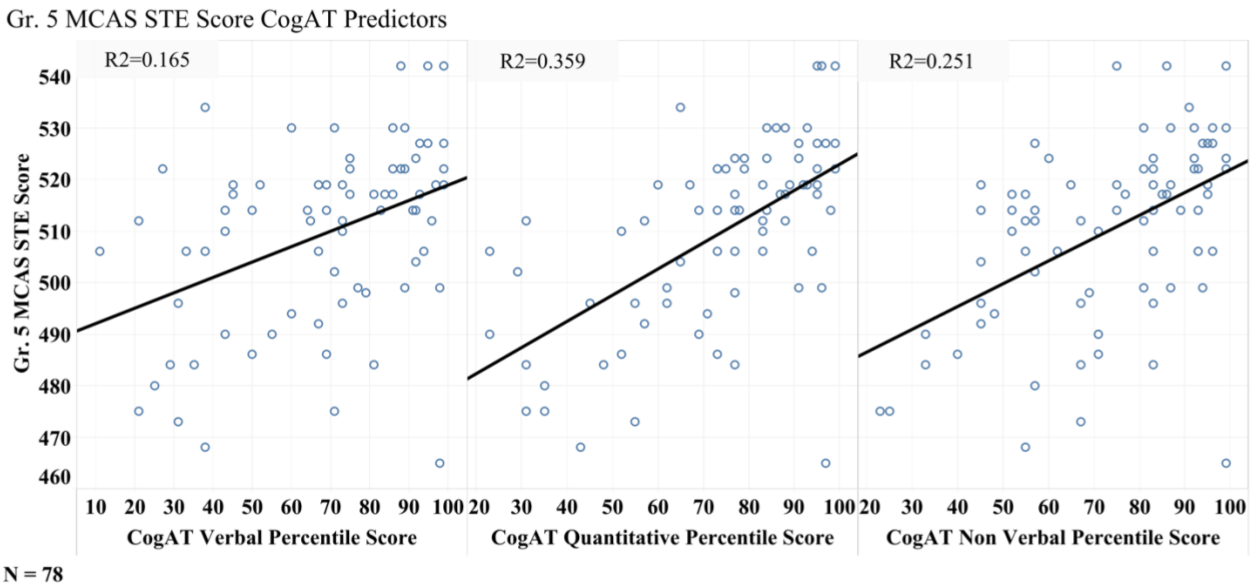
District B Grade 5 MCAS STE Score vs MCAS Predictors



N = 78

Figure 46

District B Grade 5 MCAS STE Score vs CogAT Predictors



The following tables show the result of linear regression. The highlighted cells represent scatterplots displayed in this section. Please refer to Appendix H to view the remaining scatterplots.

Table 8

District A Quantitative Score Analysis

Figure #	Dependent	Independent	Coefficient	R-Squared
Figure 40	Gr. 5 MCAS STE Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.470	0.334
Figure 40	Gr. 5 MCAS STE Score	Gr. 3 CogAT Quantitative Percentile Score	0.483	0.341
Figure 40	Gr. 5 MCAS STE Score	Gr. 3 CogAT Verbal Percentile Score	0.523	0.377
Figure 39	Gr. 5 MCAS STE Score	Gr. 3 MCAS ELA	0.702	0.412
Figure 39	Gr. 5 MCAS STE Score	Gr. 3 MCAS Math	0.724	0.459
Figure 38	Gr. 5 MCAS Math Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.446	0.407
Figure 38	Gr. 5 MCAS Math Score	Gr. 3 CogAT Quantitative Percentile Score	0.481	0.453
Figure 38	Gr. 5 MCAS Math Score	Gr. 3 CogAT Verbal Percentile Score	0.437	0.349
Figure 37	Gr. 5 MCAS Math Score	Gr. 3 MCAS ELA	0.590	0.390

Figure #	Dependent	Independent	Coefficient	R-Squared
Figure 37	Gr. 5 MCAS Math Score	Gr. 3 MCAS Math	0.732	0.632
Figure 36	Gr. 5 MCAS ELA Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.377	0.266
Figure 36	Gr. 5 MCAS ELA Score	Gr. 3 CogAT Quantitative Percentile Score	0.419	0.305
Figure 36	Gr. 5 MCAS ELA Score	Gr. 3 CogAT Verbal Percentile Score	0.481	0.404
Figure 35	Gr. 5 MCAS ELA Score	Gr. 3 MCAS ELA	0.704	0.527
Figure 35	Gr. 5 MCAS ELA Score	Gr. 3 MCAS Math	0.640	0.449
Figure 52	Gr. 3 MCAS Math Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.503	0.439
Figure 52	Gr. 3 MCAS Math Score	Gr. 3 CogAT Quantitative Percentile Score	0.596	0.556
Figure 52	Gr. 3 MCAS Math Score	Gr. 3 CogAT Verbal Percentile Score	0.539	0.450
Figure 51	Gr. 3 MCAS ELA Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.374	0.253
Figure 51	Gr. 3 MCAS ELA Score	Gr. 3 CogAT Quantitative Percentile Score	0.447	0.338
Figure 51	Gr. 3 MCAS ELA Score	Gr. 3 CogAT Verbal Percentile Score	0.554	0.505

n = 953 (sample complete tests), all values at *p < 0.0001 and are significant ***

Table 9

District B Quantitative Score Analysis

Figure #	Dependent	Independent	Coefficient	R-Squared	P-value
Figure 46	Gr. 5 MCAS STE Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.442	0.251	0.0001***
Figure 46	Gr. 5 MCAS STE Score	Gr. 3 CogAT Quantitative Percentile Score	0.508	0.359	0.0001***
Figure 46	Gr. 5 MCAS STE Score	Gr. 3 CogAT Verbal Percentile Score	0.298	0.165	0.000358***
Figure 45	Gr. 5 MCAS STE Score	Gr. 3 MCAS ELA	0.534	0.251	0.0001***
Figure 45	Gr. 5 MCAS STE Score	Gr. 3 MCAS Math	0.531	0.370	0.0001***
Figure 44	Gr. 5 MCAS Math Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.448	0.297	0.0001***
Figure 44	Gr. 5 MCAS Math Score	Gr. 3 CogAT Quantitative Percentile Score	0.381	0.238	0.0001***
Figure 44	Gr. 5 MCAS Math Score	Gr. 3 CogAT Verbal Percentile Score	0.178	0.0657	0.0254*
Figure 43	Gr. 5 MCAS Math Score	Gr. 3 MCAS ELA	0.513	0.268	0.0001***
Figure 43	Gr. 5 MCAS Math Score	Gr. 3 MCAS Math	0.611	0.542	0.0001***
Figure 42	Gr. 5 MCAS ELA Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.238	0.071	0.0244*

Figure #	Dependent	Independent	Coefficient	R-Squared	P-value
Figure 42	Gr. 5 MCAS ELA Score	Gr. 3 CogAT Quantitative Percentile Score	0.249	0.0883	0.00867**
Figure 42	Gr. 5 MCAS ELA Score	Gr. 3 CogAT Verbal Percentile Score	0.198	0.0743	0.0172*
Figure 41	Gr. 5 MCAS ELA Score	Gr. 3 MCAS ELA	0.431	0.163	0.000791***
Figure 41	Gr. 5 MCAS ELA Score	Gr. 3 MCAS Math	0.401	0.217	0.0001***
Figure 59	Gr. 3 MCAS Math Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.476	0.226	0.0001***
Figure 59	Gr. 3 MCAS Math Score	Gr. 3 CogAT Quantitative Percentile Score	0.437	0.205	0.0001***
Figure 59	Gr. 3 MCAS Math Score	Gr. 3 CogAT Verbal Percentile Score	0.261	0.0965	0.00705**
Figure 58	Gr. 3 MCAS ELA Score	Gr. 3 CogAT Non-Verbal Percentile Score	0.376	0.212	0.0001***
Figure 58	Gr. 3 MCAS ELA Score	Gr. 3 CogAT Quantitative Percentile Score	0.372	0.188	0.000305***
Figure 58	Gr. 3 MCAS ELA Score	Gr. 3 CogAT Verbal Percentile Score	0.242	0.119	0.00247**

N= 78 (sample complete tests), * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

The linear regression results exhibit that there is a high degree of correlation between earlier test scores and later ones (see Appendix C). These numbers can be used to predict an MCAS score based on either the CogAT score or an earlier MCAS score. The following are observations from Table 8 and Table 9.

The analysis displays that some scores have a larger impact on the resulting prediction than others. For example, in District A, CogAT Verbal score has a 55% effect on 3rd grade's MCAS ELA, where the CogAT Nonverbal has a 37% effect.

The analysis also displays that grade 3 MCAS scores have a higher predictive power to the grade 5 MCAS scores than the CogAT scores. For example, in District B, grade 3 MCAS ELA score has a 43% impact on 5th grade MCAS ELA which is 10-15 points higher than any of the CogAT scores.

The result of the regression analysis shows that CogAT scores for District A have a higher coefficient for predicting MCAS scores than District B's, meaning that changes in CogAT scores for District A have a larger impact than the respective CogAT scores in District B.

Question 1B

What is the relationship between earlier test scores and growth trajectory observed in the 5th grade MCAS performance?

Hypothesis

It would seem reasonable to assume if students performed well in an earlier test, they would continue to perform well in the later tests and demonstrate growth.

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest (N=953). The scores of interest include MCAS ELA (3rd and 5th), Math (3rd and 5th), STE (5th); ELA growth and Math and STE in the 5th grade; CogAT verbal, quantitative, and nonverbal. Students who were missing one or more scores were removed. The total number of students for this exercise was 953 (N=953).

District B provided complete data (MCAS and CogAT) for a total of 78 students (N=78).

The dataset provides a metric for each student as an indicator of their growth. This metric was developed by The Massachusetts Department of Elementary and Secondary Education indicating and communicating student growth, "Student Growth Percentile/SGP" (see Appendix C). This calculation appears to have been carefully thought out and is comprehensive. It is solid and valuable to use in order to answer this question. As a part of this examination linear regression has been utilized to explore the relationship between earlier scores and MCAS growth percentiles.

Examination

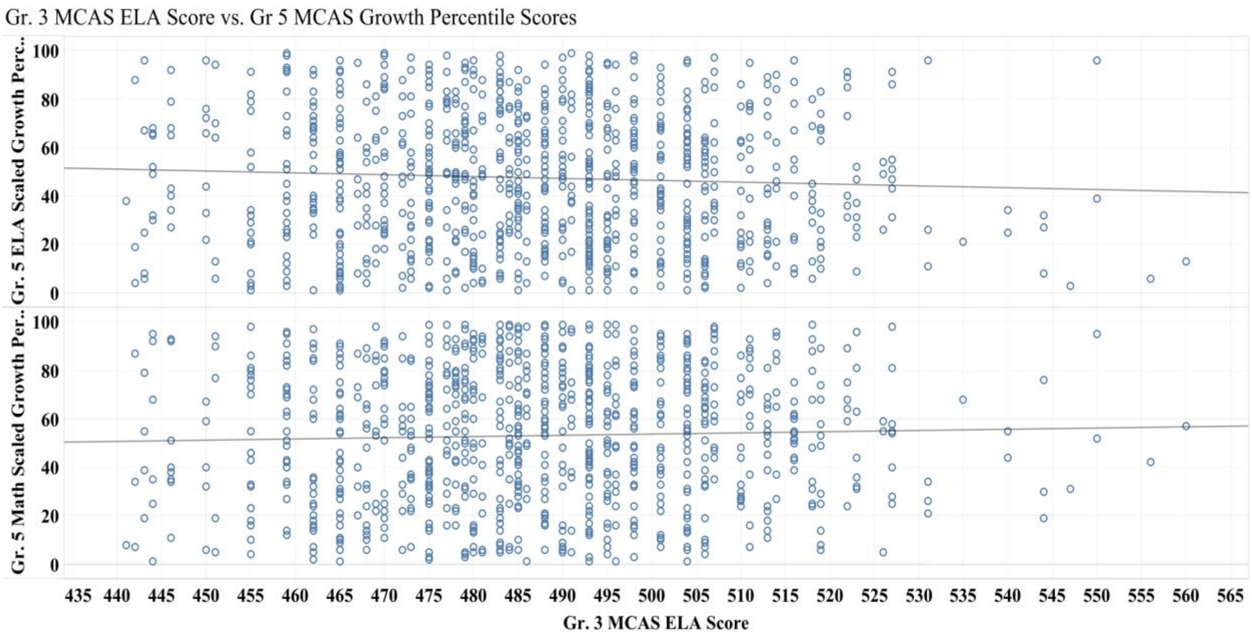
Data was examined using two different methods. Scatter plots were used to depict a visual representation of the data, allowing the reader to see the relationship between the input (earlier test) and output (MCAS Growth Percentile).

Linear regression was used to provide a mathematical and quantitative measure of the relationship between the two. Linear regression results provide a few values, with the p-value as a main indicator of the statistical significance of the result. In our case, we are using a widely accepted value of 5% (0.05) to show whether the result was significant or not. The other value of interest is the coefficient, which describes how closely related the dependent variable is to the independent one. In brief, it describes the scope of change in output, given a change in the input.

The following sample scatterplots demonstrate the visual representation of 3rd grade ELA score to the 5th grade Scaled Growth Percentile (SGP). A complete set of scatterplots can be seen in Appendix H.

Figure 47

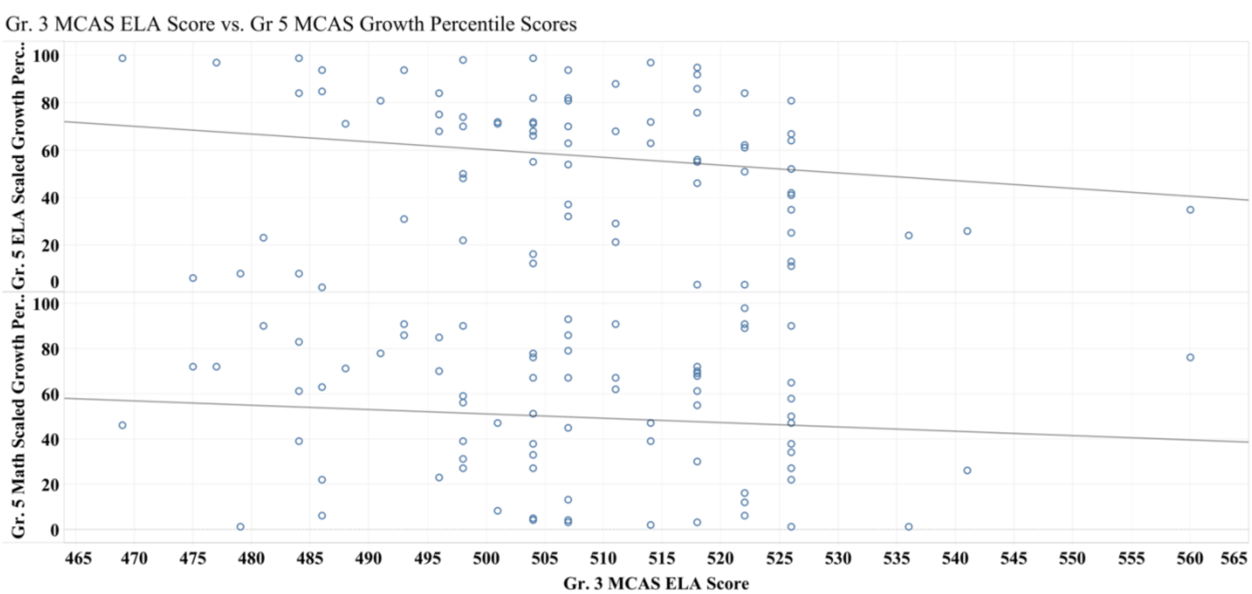
District A 3rd grade MCAS ELA Score vs. 5th grade MCAS SGPs



N = 953

Figure 48

District B 3rd grade MCAS ELA Score vs. 5th grade MCAS SGPs



N = 78

In examining the graphs, none of the earlier scores show a high degree of correlation, if any, to MCAS growth numbers in 5th grade. A linear regression is run, nevertheless, to mathematically review.

Table 10

District A Quantitative Score Analysis

Dependent	Independent	Coefficient	R-Squared	P-value
Gr. 5 Math Scaled Growth Percentile	Gr. 3 CogAt Non-Verbal Percentile Score	0.122	0.0143	0.000408***
Gr. 5 Math Scaled Growth Percentile	Gr. 3 CogAt Quantitative Percentile Score	0.0879	0.00723	0.0125**
Gr. 5 Math Scaled Growth Percentile	Gr. 3 CogAt Verbal Percentile Score	0.0475	0.00201	0.188
Gr. 5 Math Scaled Growth Percentile	Gr. 3 MCAS ELA Score	0.0502	0.0013	0.295
Gr. 5 Math Scaled Growth Percentile	Gr. 3 MCAS Math Score	0.0409	0.000954	0.365
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 CogAt Non-Verbal Percentile Score	0.104	0.0110	0.00205**
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 CogAt Quantitative Percentile Score	0.0341	0.00112	0.328
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 CogAt Verbal Percentile Score	0.0581	0.00315	0.0992
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 MCAS ELA Score	-0.0767	0.00321	0.103
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 MCAS Math Score	0.0662	0.00260	0.133

n = 953 (sample complete tests), * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Table 11

District B Quantitative Score Analysis

Dependent	Independent	Coefficient	R-Squared	P-value
Gr. 5 Math Scaled Growth Percentile	Gr. 3 CogAt Non-Verbal Percentile Score	0.107	0.00540	0.525
Gr. 5 Math Scaled Growth Percentile	Gr. 3 CogAt Quantitative Percentile Score	0.0214	0.000222	0.898
Gr. 5 Math Scaled Growth Percentile	Gr. 3 CogAt Verbal Percentile Score	-0.107	0.00737	0.458
Gr. 5 Math Scaled Growth Percentile	Gr. 3 MCAS ELA Score	-0.192	0.01160	0.354
Gr. 5 Math Scaled Growth Percentile	Gr. 3 MCAS Math Score	-0.230	0.0244	0.178
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 CogAt Non-Verbal Percentile Score	0.0998	0.00472	0.558
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 CogAt Quantitative Percentile Score	0.0211	0.000227	0.896

Dependent	Independent	Coefficient	R-Squared	P-value
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 CogAt Verbal Percentile Score	0.119	0.00935	0.403
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 MCAS ELA Score	-0.328	0.03502	0.105
Gr. 5 ELA Scaled Growth Percentile	Gr. 3 MCAS Math Score	0.0777	0.00291	0.643

N= 78 (sample complete tests), * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

District B shows no relation between earlier scores and growth as calculated by the Department of Education (DOE).

District A shows a weak relationship between CogAT Nonverbal and Math Scaled Growth Percentile (SGP). However, the relationship is weak and probably not material in practice.

Question 1 analyzed quantitative scores such as scores in growth against other quantitative factors such as CogAT and MCAS scores, longitudinally.

Question 2

Examination of the datasets: conduct analysis of available data to examine the distribution of MCAS and CogAT scores against attributes of gender, economically disadvantaged, and anonymized school ID across two districts.

Only District A provided gender and economic status; therefore, District B will not be included in that section of the analysis. District B is however, included in Question 2g.

Question 2A

Are there observational similarities or differences between genders with regards to test scores?

Hypothesis

A significant difference in performance between gender scores is not expected.

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. The total number of students for this exercise was therefore 953 (N=953).

For this test, Standard Age Score (SAS) CogAT scores were used for District A. SAS numbers were chosen for these tests since they are more granular than Percentile values. Comparison with District B, which only provided Percentile values, is not possible due to lack of gender information.

Examination

The data was divided into two groups based on the Gender attribute. From the total of 953 students, 492 were identified as male and 461 were identified as female. For every group the following averages were calculated:

Field	Description
CogAT Verbal Standard Age Score (SAS)	3rd Grade CogAT score for verbal test
CogAT Quantitative Standard Age Score (SAS)	3rd Grade CogAT score for quantitative test
CogAT NonVerbal Standard Age Score (SAS)	3rd Grade CogAT score for non-verbal test
Gr. 3 MCAS ELA Score	3rd Grade MCAS score for ELA
Gr. 3 MCAS Math Score	3rd Grade MCAS score for Math
Gr. 5 MCAS ELA Score	5th Grade MCAS score for ELA
Gr. 5 MCAS Math Score	5th Grade MCAS score for Math
Gr. 5 MCAS STE Score	5th Grade MCAS score for STE

The average of every score was compared between the Male and Female populations. Single factor ANOVA analysis at alpha = 0.05 was used to show whether differences between the populations are significant or not.

The following table displays the results of the ANOVA tests and the significance of differences.

Table 12

ANOVA Test for Gender Performance Differences

Test	Male Average Score	Female Average Score	F	p-Value	F critical	Assessment
CogAT Verbal Standard Age Score	93.494	96.234	9.425	0.002**	3.851	F Average higher by 2.74
CogAT Quantitative Standard Age Score	99.323	97.275	5.503	0.019**	3.851	M Average higher by 2.048
CogAT Non-Verbal Standard Age Score	98.520	100.321	3.838	0.050*	3.851	F Average higher by 1.801
Gr. 3 MCAS ELA	484.724	489.952	17.418	0.000***	3.851	F Average higher by 5.229
Gr. 3 MCAS Math	487.226	488.239	0.575	0.449	3.851	F Average higher by 1.013
Grade 5 MCAS ELA	488.144	494.382	25.441	0.000***	3.851	F Average higher by 6.237
Grade 5 MCAS Math	490.726	492.386	1.847	0.174	3.851	F Average higher by 1.661
Grade 5 MCAS STE	488.752	487.475	0.780	0.377	3.851	M Average higher by 1.277

n = 953, * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

This analysis was done at a 5% confidence level with alpha set to 0.05. From the ANOVA Test for Gender Performance Differences, it is deduced that female students scored higher in the areas of CogAT verbal and 3rd grade MCAS ELA, as well as on the 5th grade MCAS ELA. Male students scored higher on the 3rd grade CogAT quantitative assessment. There were no significant differences observed in the area of CogAT nonverbal and the 5th grade MCAS Math and STE performance, respectively.

Question 2B

What percentage of the students who were identified as either male or female, did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) expectations? What percentage met (M) expectations? What percentage exceeded (E) expectations?

Hypothesis:

MCAS performance of male and female students will be similar across the two grade levels.

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. Therefore, the total number of students for this exercise was 953 (*n*= 953).

Examination

For each one of the five MCAS tests, the students were grouped by their reported gender.

The percentage of students that fall in a particular achievement level was calculated. Exceeding or Meeting Expectations were combined.

Table 13

MCAS Achievement Levels Based on the Gender Attribute

Percentage of Achievement Level by Gender	Exceeding or Meeting Expectations	Meeting Expectations	Partially Meeting Expectations	Not Meeting Expectations
Gr. 3 MCAS ELA All Students	25.92 % (1.47 + 24.45)	24.45%	55.72%	18.36%
Female	30.37% (2.39 + 27.98)	27.98%	55.75%	13.88%
Male	21.75 % (0.61+ 21.14)	21.14%	55.69%	22.56%
Gr. 3 MCAS Math All Students	30.01% (1.68+ 28.33)	28.33%	49.63%	20.36%
Female	30.6% (1.52+ 29.07)	29.07%	52.93%	16.49%

Percentage of Achievement Level by Gender	Exceeding or Meeting Expectations	Meeting Expectations	Partially Meeting Expectations	Not Meeting Expectations
Male	29.47% (1.83+ 27.64)	27.64%	46.54%	23.98%
Gr. 5 MCAS ELA All Students	32.63% (1.47 + 31.16)	31.16%	54.35%	13.01%
Female	37.31% (2.17+ 35.14)	35.14%	54.01%	8.68%
Male	28.25% (0.81+ 27.44)	27.44%	54.67%	17.07%
Gr. 5 MCAS Math All Students	34.42% (1.26+ 33.16)	33.16%	54.04%	11.54%
Female	34.28% (0.87+ 33.41)	33.41%	57.05%	8.68%
Male	34.56 % (1.63+ 32.93)	32.93%	51.22%	14.23%
Gr. 5 MCAS STE All Students	29.9% (2.20 + 27.7)	27.70%	49.95%	20.15%
Female	27.77% (1.52+ 26.25)	26.25%	54.01%	18.22%
Male	31.92% (2.85 + 29.07)	29.07%	46.14%	21.95%

n = 953

This observation provides a closer view of gender differences in terms of performance (see the shaded areas in Table 13). For 3rd and 5th grade MCAS ELA, there is a higher percentage of female students in the Exceeding or Meeting expectations (E or M) group as well as a lower percentage of female students in the Not Meeting (NM) expectations, as compared to the male students. At the same time the male students demonstrated a higher percentage in Exceeding or Meeting (E or M) expectations in the 5th grades MCAS STE scores, while they also had a higher percentage in Not Meeting (NM) expectations in the areas of MCAS Math and STE. Overall, the percentage of female students in the Not Meeting expectations is less than male students across the five performance assessments.

Question 2C

Are there observational similarities or differences between genders with regards to MCAS growth from grade 3 to grade 5?

Hypothesis

A significant difference between gender score growth is not expected.

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. The total number of students for this exercise was therefore 953 (N=953).

For this test, MCAS Scaled Growth Percentile (SGP) for 5th grade ELA and Math were used for District A

Examination

The data was divided into two groups based on the Gender attribute. From the total of 953 students, 492 were identified as male and 461 were identified as female.

A statistical single factor ANOVA test was performed to detect a difference in average growth in 5th grade between the two indicated genders.

Table 14

MCAS Growth Based on the Gender Attribute

	Male Average	Female Average	F	p-Value	F crit	Significantly Different?
Grade 5 MCAS ELA Scaled Growth Percentile	44.0650	49.948	11.462	0.000739***	3.851	Yes
Grade 5 MCAS Math Scaled Growth Percentile	51.671	55.584	4.816	0.0284*	3.851	Yes

n = 953, * p < 0.05, ** p < 0.01, ***p < 0.001

It is interesting to see the results do not support the hypothesis for this question. The data shows that on average female students present a higher growth in both MCAS ELA and Math tests. It is worth noting that the female students had a higher test score in ELA MCAS in the 3rd grade to begin with.

Question 2D

Are there observational similarities and differences between students identified as economically disadvantaged (EcoDis) and students who were not economically disadvantaged (non-EcoDis)?

Hypothesis:

Based on recent brain research, lower scores are expected for the economically disadvantaged (EcoDis) students as compared to those who were not economically disadvantaged (non-EcoDis).

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. Therefore, the total number of students for this exercise was 953 (N=953).

Examination:

The data was divided into two groups based on the economic attribute. Of the 953 students, 382 were not economically disadvantaged and 571 students were marked as economically disadvantaged.

Table 15

ANOVA Test for Economic Performance Differences

Test	Eco Dis Average	Not Eco Dis Average	F	p-Value	F crit	Assessment	Significantly Different?
CogAt Verbal Standard Age Score	92.996	97.545	25.379	0.0001***	3.851	Eco-Dis Average lower by 4.548	Yes
CogAT Quantitative Standard Age Score (SAS)	96.291	101.385	33.719	0.0001***	3.851	Eco-Dis Average lower by 5.094	Yes
CogAT Nonverbal Standard Age Score (SAS)	97.536	102.165	24.932	0.0001***	3.851	Eco-Dis Average lower by 4.629	Yes
Gr. 3 MCAS ELA Scaled Score	484.380	491.547	31.945	0.0001***	3.851	Eco-Dis Average lower by 7.167	Yes

Test	Eco Dis Average	Not Eco Dis Average	F	p-Value	F crit	Assessment	Significantly Different?
Gr. 3 MCAS Math Scaled Score	484.448	492.599	37.174	0.0001***	3.851	Eco-Dis Average lower by 8.151	Yes
Gr. 5 MCAS ELA Scaled Score	488.105	495.730	36.998	0.0001***	3.851	Eco-Dis Average lower by 7.625	Yes
Gr. 5 MCAS Math Scaled Score	488.608	495.895	35.419	0.0001***	3.851	Eco-Dis Average lower by 7.288	Yes
Gr. 5 MCAS STE Scaled Score	484.699	493.270	34.989	0.0001***	3.851	Eco-Dis Average lower by 8.571	Yes

n = 953, * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Based on the ANOVA analysis, it is apparent that economically disadvantaged (EcoDis) students demonstrated lower scores across all the tests. The lower score differences are statistically significant based on the low p-value and F value being much larger than F-Crit. The score difference between the two groups ranged from 4.6 in the 3rd grade CogAT verbal, to 8.6 in the 5th grade MCAS STE, respectively. This result means they scored barely above the state's partially meeting (PM) expectation range of 470-499 in all MCAS assessments.

Question 2E

What percentage of the students who were identified as economically disadvantaged (EcoDis), did not meet (NM) the MCAS expectations in the district? What percentage partially met (PM) the MCAS expectations? What percentage met (M) the MCAS expectations? What percentage exceeded (E) expectations?

Hypothesis:

Given the distribution of the dataset in this particular district, of the economically disadvantaged students, I would expect a high percentage to fall in either Needing Improvement or Partially Meeting the 3rd and 5th grade MCAS expectations.

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. Therefore, the total number of students for this exercise was 953 (N=953).

Examination

For each one of the five MCAS tests, the students were grouped by the economically disadvantaged (EcoDis) attribute. Their MCAS scores were assigned an achievement level label based on ranges provided by the Department of Elementary and Secondary Education (DOE MCAS Parent/Guardian Report, 2021).

The percentage of students that fall in a particular achievement level was calculated. Exceeding or Meeting Expectations were combined.

Table 16

MCAS Achievement Levels Based on the Economically Disadvantaged Attribute

Percentage of Achievement Level by Economic Status	Exceeding or Meeting Expectations	Meeting Expectations	Partially Meeting Expectations	Not Meeting Expectations
Gr. 3 MCAS ELA All Students	25.92% (1.47 + 24.45)	24.45%	55.72%	18.36%
EcoDis	21.9% (1.23 + 20.67)	20.67%	56.39%	21.72%
Not EcoDis	31.93% (1.83 + 30.10)	30.10%	54.71%	13.35%
Gr. 3 MCAS Math All Students	30.0% (1.68 + 28.33)	28.33%	49.63%	20.36%
EcoDis	24.87% (1.75 + 23.12)	23.12%	48.86%	26.27%
Not EcoDis	37.7% (1.57+ 36.13)	36.13%	50.79%	11.52%
Gr. 5 MCAS ELA All Students	32.63% (1.47+ 31.16)	31.16%	54.35%	13.01%
EcoDis	27.67% (0.35 + 27.32)	27.32%	55.34%	16.99%
Not EcoDis	40.05% (3.14 +36.91)	36.91%	52.88%	7.07%
Gr. 5 MCAS Math All Students	34.42% (1.26 + 33.16)	33.16%	54.04%	11.54%
EcoDis	28.9% (0.53+ 28.37)	28.37%	56.04%	15.06%

Percentage of Achievement Level by Economic Status	Exceeding or Meeting Expectations	Meeting Expectations	Partially Meeting Expectations	Not Meeting Expectations
Not EcoDis	42.67% (2.36 + 40.31)	40.31%	51.05%	6.28%
Gr. 5 MCAS STE All Students	29.9% (2.20+ 27.7)	27.70%	49.95%	20.15%
EcoDis	25.04% (1.75+ 23.29)	23.29%	50.09%	24.87%
Not EcoDis	37.17% (2.88 + 34.29)	34.29%	49.74%	13.09%

n = 953

The results of the One-way ANOVA test showed that the average test scores of the economically disadvantaged (EcoDis) students were lower, and these percentages (highlighted) confirm that there is a higher percentage of the economically disadvantaged students (EcoDis) in the Not Meeting Expectations (NM) across grades and test categories. For the meeting expectations (M) group, the percentage of EcoDis students is consistently 8 or more points lower than the Non-EcoDis. An observation of the lower achievement groups across grades and test categories reveals a wider gap.

The percentage of EcoDis and Non-EcoDis students is similar in the partially meeting expectations group, where percentage of EcoDis students is consistently 10 points higher than the non-EcoDis. This observed trend shows that although a similar percentage of students are in the exceeding (E) expectations group, a higher percentage of EcoDis students are in the lower achievement groups.

To continue looking at this data longitudinally across to the 5th grade MCAS, the gap also becomes obvious in the exceeding (E) expectations category. For example, in the 5th grade MCAS ELA, 3.1% of non-EcoDis students fell in the Exceeding expectations vs. the 0.35 percent of EcoDis group. As for the 5th grade MCAS Math, 2.36% of the Non-EcoDis students scored exceeding (E) expectations vs. only 0.53% of the EcoDis students Exceeding expectations (E).

Question 2F

Are there similarities or differences observed in MCAS growth percentile from grade 3 to grade 5 with regards to economic status?

Hypothesis

Economically disadvantaged will likely display lower growth.

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. The total number of students for this exercise was therefore 953 (N=953).

For this test, MCAS SGP (Student Growth Percentile) for 5th grade ELA and Math were used for District A

Examination

The data was divided into two groups based on the economically disadvantaged (EcoDis) attribute. Of the total of 953 students, 571 were identified as economically disadvantaged (EcoDis) and 382 were identified as not.

A statistical single factor ANOVA test was performed to detect a difference in average growth in 5th grade between the two indicated economic groups. For every group the following averages were calculated:

Table 17

MCAS Growth Based on the Economically Disadvantaged Attribute

	EcoDis Average	Non-EcoDis Average	F	p-Value	F crit	Significantly Different?
Gr. 5 MCAS ELA Scaled Growth Percentile	45.944	48.356	1.834	0.176	3.851	No

	EcoDis Average	Non-EcoDis Average	F	p-Value	F crit	Significantly Different?
Gr. 5 MCAS Math Scaled Growth Percentile	52.201	55.599	3.488	0.0621	3.851	No

n = 953, * p < 0.05, ** p < 0.01, ***p < 0.001

The data indicates that on average there are no significant differences between the MCAS score growth of the economically disadvantaged/EcoDis and not economically disadvantaged/non-EcoDis students. This indicates that everyone can grow, regardless of their economic status. The implication is that the economically disadvantaged on average had lower scores than the non-economically disadvantaged students and would need higher level and more effective interventions to meet benchmarks.

Question 2G

What type of growth percentile is observed in each of the districts' schools?

Hypothesis:

Comparing MCAS growth between various schools in each district may exhibit differences.

Dataset:

District A- of the 1280 student data that was provided by District A, 953 had complete CogAT scores and 3rd and 5th grade MCAS scores. The schools for these 953 students were used for this analysis (*n*=953). This district contains 11 schools.

District B- 78 student data was provided. The schools for these 78 students were used for this analysis (*N*=78). This district contains 6 schools.

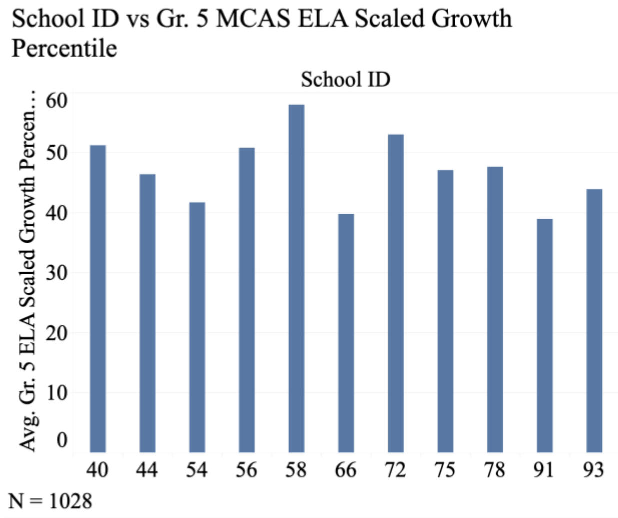
To anonymize the data, each school was given a random numeric value.

Examination:

Each district provided both ELA and Math Student Growth Percentile (SGP). Since SGPs are calculated statewide, they are useful in comparing the schools within the districts and then the districts together. The following charts show the average SGP for each school.

Figure 49

District A School vs. ELA SGP



District A School vs. Math SGP

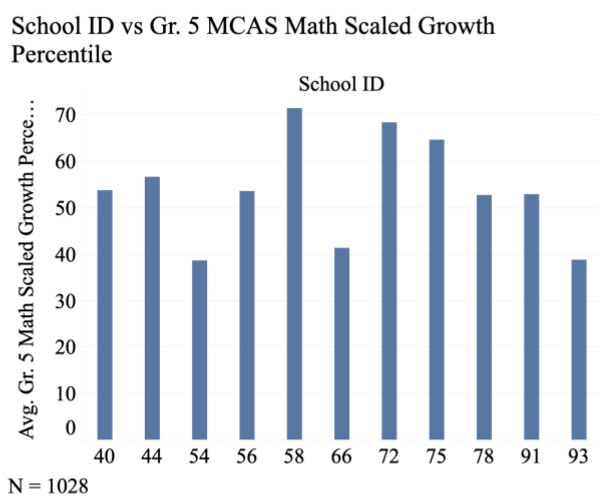
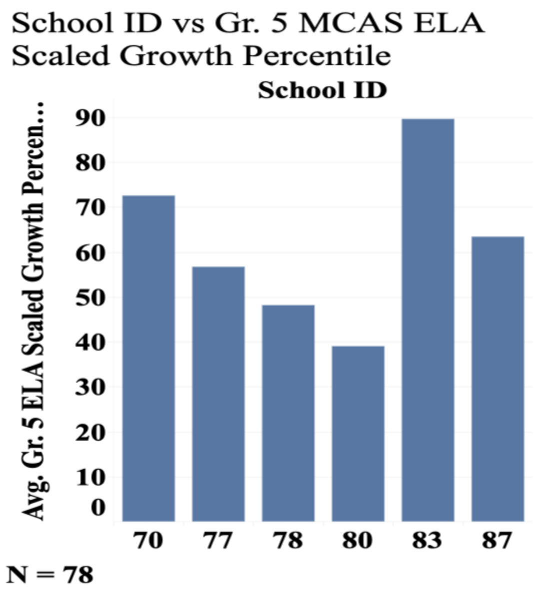
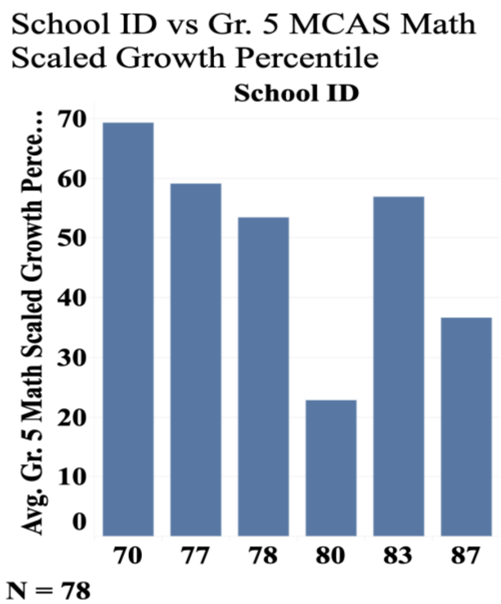


Figure 50

District B School vs. ELA SGP



District B School vs. Math SGP



According to Mass DOE the SGP "MCAS shows how each student is achieving relative to state standards". It is calculated statewide and is a good representative of a student's growth compared to every other similar student in the state. “Typical student growth percentiles are between about 40 and 60 on most tests.” Across each district, the average growth numbers fall in the 40-60 number that the Massachusetts Department of Education, DOE finds typical. However, some schools within each District are consistently lower or higher compared to their peer schools for both ELA and Math MCAS tests.

Question 2 analyzed measurable factors such as score and growth against the available non-quantitative data: gender, economically disadvantaged, and individual schools within a district. The findings here warrant future longitudinal studies across a few years in schools, in each of the districts.

Question 3

Neuroscience and Education: use a neuroscience lens to examine quantitative performance data and non-quantitative attributes data to observe how the results can inform neuromyth free implications related to the field of education.

Question 3A

Examination of quantitative performance data: What kind of plausible insights from the instruments (Next Generation MCAS and the CogAT) can be reflected in the results?

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. The total number of students for this exercise was 953 (n= 953).

District B provided complete data (MCAS and CogAT) for a total of 78 students (N= 78).

Examination of Quantitative Results

Employing scatterplots to detect relationships and linear regressions for a closer examination, Question 1A of this dissertation (longitudinal performance between earlier and later tests) found a high degree of correlation between the scores across the two grade levels, academic areas, and assessment instruments in two districts. A higher degree of correlation between later and earlier scores were found to predict 5th grade scores based on 3rd grade performance on both the MCAS and the CogAT. As seen in Question 1B, it was found that individual growth could not be measured using these assessment tools, based on Student Growth Percentile, SGP (see Tables 7, 8, 9, 10, and Figures 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 51 to 64, respectively).

Due to the high degree of correlation observed between the two test instruments (MCAS and CogAT), they both appear to measure performance in the areas of English Language Arts, Mathematics, Science Technology Engineering/STE and the CogAT Verbal, Quantitative, and Nonverbal batteries. Therefore, Grade 3 MCAS tests (ELA and Math) and CogAT tests (verbal, quantitative, and nonverbal) can both be used to predict future (grade 5) performance. Overall, the first question of this study found that both the MCAS and the CogAT tests measure performance and the MCAS is a better predictor of future performance-based assessment than the CogAT.

The Next Generation MCAS summative assessment instrument is performance-based, embedding achievement and growth in one assessment tool (Massachusetts DESE, n.d.) to assess students of in their grade levels based on their level of achievement relative to state standards.

Riverside Publishing (n.d.) suggests the Cognitive Abilities Test or the CogAT tests students' abilities in three different domains of verbal, quantitative, and nonverbal batteries.

Measuring reasoning ability, the CogAT emphasizes grouping students by their "learning styles" and matching the learning styles to "teaching methods." Educators are provided with reports that speak to student's scores and learning styles after the completion of test batteries (Riverside Publishing, n.d.).

The results of two assessments (MCAS and CogAT) scores in grade 3 (2017) and in grade 5 (2019) were analyzed to examine correlations and growth measures across two academic grade levels (3rd and 5th). Introduction and literature review chapters (1 and 2) of this dissertation were consulted in understanding the results from data analysis.

Integrative Review of Neuroscience Research

Utilizing an integrative review based on neuroscience literature (Chapters 1 and 2), CogAT's suggestion about testing for "learning styles" and preparing teachers with individual student's "learning profiles" is considered a neuromyth. As seen in Table 19: *Unpacking the Top 5 Neuromyths in the Field of Education,* the theory of "learning styles" lacks scientific evidence and has been proven false by neuroscience (Dandy & Bendersky, 2014; Dekker et al., 2012; Geaker, 2018; Riener & Willingham, 2010; Rousseau, 2021; Torrijos-Muelas, 2021). Table 19, unpacks the most popular neuromyths that have currently contaminated the field of education, present and perpetuating in the classrooms, children's literature, teacher training, marketing, and educator's preservice training and professional development.

Neuroscience findings reveal that learning, an extremely complex process that is highly individualized (McFarland, 2017), involves many interactions including abilities based on genetics and environmental factors (section 2 of Chapter 2), engagement during tasks, emotions, interpersonal synchrony, teacher likability, pedagogy, attention based on content interest (section 1 of Chapter 2, and Figure 15), and first and foremost, feeling safe and free from fear and anxiety (section 3 of Chapter 2). Consequently, performance can be predicted based on metrics using a spectrum of formative and summative assessments available to educators, to inform them of the need of mediation when necessary and utilizing preventive and intervention strategies to improve their students' future performance. From a neuroscience perspective, measuring ability is much more complex due to the variability, the dynamic underpinnings, and function of the brain at a given point in time. Narrowing the definition of ability to single performance constructs at a given time reduces the true complexity and the actual functioning of the brain (McFarland, 2017).

Accordingly, to boost student performance, confidence, feelings of attainment and achievement and well-being, student preparation is absolutely necessary (see Table 18). Neuroscience informs that repeated experience and associations strengthen neural connections, increase processing efficiency, enhance acetylcholine encoding, and lead to dopamine release in neurons gradually firing when stimulus is novel and exciting. There is a reward in applying intentional attention, demonstrating that neurons can eventually predict the reward followed by stimulus. As seen in Table 18: *Neuroscience "Wisdom" and Application to Education*, student success depends on incorporating consistent preparation methodologies based on formative and summative assessments to inform teachers' planning and facilitating engagement in learning. Providing many opportunities for learning novel content and connecting the knowledge to prior content, teachers' excitement in presenting topics (see Figure 15), and repeating information in a variety of ways and as needed are critical in the process of learning. Teachers' efforts in routinely teaching study skills while being cognizant of individual students' developmental milestone, being patient and allowing space between lessons, and most importantly relating to students with positive emotions (see Figure 15), which augment attention and increase flexibility in learning, are of paramount importance in thinking about pedagogy (Blanchette et al., 2018; Callan & Schweighofer, 2010; Hong & Aqui, 2004; Jasanoff, 2018; Kania et al., 2005; Renee van Kesteren & Meetrer, 2020; Rossi et al., 2015; Zaromb & Roediger, 2010).

Question 3B

Examination of non-quantitative attributes data on performance: Given our current knowledge of neuroscience, how can we use neuroscience-informed practice in the classroom?

Dataset

District A provided a total of 1280 students. For this exercise we selected a subset of students who had all the scores of interest. Students who were missing one or more scores were removed. The total number of students for this exercise was 953 (n = 953).

District B provided complete data (MCAS and CogAT) for a total of 78 students (N=78).

Examination of Quantitative Results

The results of two assessments (MCAS and CogAT) scores in 2017 and 2019 were analyzed to examine correlations and growth measures across two academic grade levels (3rd and 5th) against the attributes of gender and economic status. Provided data from District A only, was organized based on two attributes: gender (F and M) and economic status (EcoDis and non-EcoDis), and performance.

The Department of Education defines economically disadvantaged (EcoDis) students as those who “face more learning challenges than students from more affluent households,” and qualify for one or more state-administered programs (SNAP, TAFDC, DCF, and Medicaid).

In the next Generation Massachusetts Comprehensive Assessment or the MCAS, the Department of Education defines growth as a measure of change observed in an individual student over time. This summative assessment instrument is performance-based, embedding achievement and growth in one assessment tool (Massachusetts DESE, n.d.) to assess students of in their grade levels based on their level of achievement relative to state standards.

Pertinent literature from introduction and integrative literature review chapters (Chapters 1 and 2) were consulted to answer this question.

In Questions 2A–2C of this dissertation, one-way ANOVA test for gender differences was conducted, revealing some gender differences in the dataset provided from District A. It was found that students who identified as female scored higher on the 3rd and 5th grade MCAS ELA and the CogAT verbal domain, while students who identified as male scored higher on the MCAS STE and the CogAT quantitative battery. There were no significant differences observed in the MCAS Math. Overall, a higher percentage of female students demonstrated exceeding (E) and a lower percentage of them demonstrated needing improvement (NI) on the MCAS expectations, and a lower percentage of female students appeared in the not meeting (NM) MCAS category as opposed to the male students (see Tables 12, 13, and 14 respectively).

From Questions 2D-2G, a closer examination of performance between economically disadvantaged (EcoDis) students and those who were not economically disadvantaged (non-EcoDis) revealed lower performance levels of the economically disadvantaged (EcoDis) students as compared to other students (non-EcoDis) in all the performance tests in District A. The score differences between the two groups ranged from 4.6 to 8.6 point across the two performance assessments, which are barely above the state's partially meeting (PM) expectations range of 470-499 in all MCAS assessments. A further examination unveiled a disturbing widening gap seen in the economically disadvantaged (EcoDis) group in the higher grades (see Table 15, Table 16, Figure 22, and Figure 23).

Integrative Review of Neuroscience Research

From Questions 2A–2C, a closer examination of gender differences informed that there are some developmental differences between the two genders in terms of performance assessment, with the female students presenting an increase in developmental maturity in the primary school grades, observed in particular, on the MCAS ELA, the CogAT verbal, and in terms of overall growth performance. The findings from Question 2A speak to the gender differences observed in terms of developmental trajectories in this age range.

Developmental neuroscience informs that the timing of development in children is nonlinear and varies based on many factors (Anderson et al., 2019). In this case, some differences were noted in the children's development in terms of their gender. According to Kolb (as cited in Anderson et al., 2019), the female brain tends to develop faster in childhood years, as seen on MRI studies where the volume of grey matter in girls peaks at around age 10-11, but not until age 12 in boys. The degree of connectivity in parietal lobes also corresponds to age 10 in girls versus age 12 in boys (Klingberg, 2013). In addition, more dendritic volumes have been observed in females in this age group. Patterns of greater bilateral cerebral activation have been recorded by fMRI studies in female children. In a study which examined cognitive, motor, and academic development of 95 students in the 3rd grade, Zayed and Jansen (2018) found small gender differences, where girls performed higher in one of the working memory tests, and boys demonstrated higher performance in the coordination motor test. In addition, they observed significant correlation between math and science performance and coordination in motor tasks.

The findings on the economically disadvantaged (EcoDis) students in this examination are not new. Meeting the needs of this group of students and providing effective interventions has been at the forefront of concerns in the field of education and in our society at large.

Neuroscience informs us by outlining the importance of early and continued enrichment, reducing toxic factors from the environment, and most importantly establishing attachment during the early years of development (Anderson et al., 2019; Cozolino, 2014). In *Biological Minds*, Jasanoff (2018) writes about the importance of the environment and the brain, an organ inseparable from the body and the environment. Our brains alone are not the only organs responsible for our behaviors and psychological states. The brain, body, and environment are tightly connected and interwoven in their interactions, therefore a more individualized approach is needed, if an effective change is to occur.

According to Anderson et al., (2019), it has been established that child neglect and abuse can reduce IQ, attention, working memory, self-regulation, and self-confidence. Brain imaging studies have confirmed reduced brain volume in both grey and white matters, and disparities in structural connectivity in children who are neglected, abused, and have experienced trauma. Specific brain regions affected include fronto-limbic networks, orbital prefrontal cortex, hippocampus, amygdala, and corpus callosum (Anderson et al., 2019). Klingberg (2013) posits that poverty can impair working memory, leading to poor classroom and test performance, especially in mathematics.

In a semi comparative study, Ghazi et al., (2012) conducted a cross-sectional examination of 529 students in Iraq, the results of which found a decline of IQ in children associated with the lack of feeling safe, mental stress, and living in toxic environments (see Figure 22). In another study of 1,065 children ages 12-16 in India, Makharia, et al., (2016) found that environmental factors such as neighborhoods, physical activity, family, income, parental occupation, education, and socioeconomic status played a profound role on the IQ the children displayed. According to Maslow's theory of motivation (see Figure 23), children cannot display the motivation to learn if their basic physiological needs, safety, and belonging have not been met. Cozolino (2014) and Gee & Casey (2015), found positive attachment schemas form throughout childhood (section 1 of Chapter 2), in particular, during the sensitive periods of development (see Figure 14). Suskind and Denworth (2022) insist on taking vital measures in early childhood for later success in school. They contend that above all else, children need two fundamental things to be successful: nurturing interactions with those around them and safety from "toxic stress" from the environment (see Appendix D). According to Anderson et al. (2019), positive interactions that are adaptive are crucial in forming healthy social development and developing an identity.

Framework

Using an integrative review approach the quantitative results of Questions 1 and 2 were carefully examined, neuroscience literature review (Chapter 2) was attentively synthesized, and reflectively applied to create a framework seen in Table 18 and Table 19

Table 18

Neuroscience "Wisdoms" in Learning: Insights from Neuroscience Applied to Education

Neuroscience "Wisdom"	Application to Education
1. REACTIVATE Revisit prior knowledge before starting a new lesson. Medial Prefrontal Cortex (MPFC) incorporates new information based on previously learned information, thereby creating a better schema that helps with memory encoding and consolation of new experiences. It also helps to guide behavior in predicting what is to come in the future. This strategy helps with memory during tests as well.	Some strategies include, K (what I know) W (what I wonder and want to know) L (what I learned) Jeopardy, Kahoot, other engaging games Quizzes Use fun and engaging strategies to keep track of students who struggle recalling previously taught information. These students may need additional assessments to further understand their processing and inform interventions. [Renee van Kesteren & Meeter, 2020; Blanchette et al., 2018; Rossi et al., 2015]
2. INTEGRATE Studying is actually good for the brain.	Implement, - Writing Assignments

Neuroscience "Wisdom"	Application to Education
Incorporate pauses several times during the study blocks to allow students to think about what they just learned and how what they learned now LINKS to what they already knew. Facilitate methods to help them ELABORATE and think of as many details as possible. Neuroplasticity is how your brain can change when you learn. Empower your students to make the neural connections stronger and gain confidence in their skills, thereby constructing self-efficacy.	- Building Visuals such as charts, Venn diagrams, and using technology tools. Do not "wallpaper" the classroom with ready-made, fancy posters. Have your students create the posters. This fosters creativity, critical thinking skills, and a sense of autonomy and ownership. - For higher academic levels, add a creative component where the student extends and elaborates the learning in developing a visual or writing product, creating a videogame, a comic strip, a Reader's Theater script, a board game, …Raise the bar for the higher-level students so they too feel challenged and have the opportunity to learn. A healthy academic struggle model is a must for all your students. [Rossi et al., 2015; Kania et al., 2005; Zaromb & Roediger, 2010; Blanchette et al., 2018]
3. REPEAT Reiterate information and ASK new questions consistently because the more the information is repeated in different contexts, the stronger and the more efficient the connections between the groups of neurons at work. Retrieve information to activate the neurons that are involved. If information becomes challenging, then the student is LEARNING new information they don't already know, and the teacher identifies the gaps in the students' knowledge base and provides interventions accordingly. Testing is good for information storage and strengthening neurons and the levels and applications might look different for different students. This process informs pedagogy. If information is unknown or difficult to recall, it is indicative of new knowledge or weak connections that have been forgotten.	Include, -Formative tests and assignments -Practice questions -Flashcards -Studying with groups -Other engaging strategies such as class games to remember information. - Develop stations where students present a concept they learned with detail within the overall theme. Embrace their courage for presenting and encourage positive feedback from peers, while facilitating useful feedback that does not come across as critical. Peer teaching is powerful! -This allows for multiple checks for understanding, thereby reducing/eliminating misconceptions. -This allows for perspective taking and inviting different strategies in a supportive learning environment. [Callan & Schweighofer, 2010; Rossi et al., 2015; Kania et al., 2005; Zaromb & Roediger, 2010; Blanchette et al., 2018]
4. ALLOW SPACE and ALTERNATE INFORMATION	Switch it up, Block schedules are great because they alternate topics and materials, and even teachers.

Neuroscience "Wisdom"	**Application to Education**
Provide breaks (and allow sleep, meaning give it a few days and return to it) in between lessons so that memory can be consolidated. For example, to complete a 3-hour task, allow three 1-hour periods instead of 3 hours all at once. This pacing boosts learning and avoids losing or forgetting the lessons.	Choose teaching 1-4 topics in a month that have some connecting points or relevance. Administer formative assessments/quizzes in between and end with a summative assessment. This will allow for enhancing learning and better prepares students for future standardized tests. Help your students eliminate the fear of test taking and embrace developmentally appropriate challenges for each student. [Callan & Schweighofer, 2010; Rossi et al., 2015; Kania et al., 2005; Zaromb & Roediger, 2010; Blanchette et al., 2018]
5. Always allow PRACTICE. Practice makes for stronger neural connections, increases confidence and self-efficacy, and can reduce (even mitigate) anxiety. It also helps you to clarify misunderstandings or misconceptions. Remember, this practice improves your craft as a teacher too. Students and teachers form stronger neural connections by practicing.	Incorporate, -Run practice sessions -Develop low-risk games where all students participate. Switch groupings for better engagement. - Increase the level of difficulty according to student's place in learning. This will increase trust and self-efficacy (having faith in one's performance), and therefore reducing anxiety. [Callan & Schweighofer, 2010; Rossi et al., 2015; Kania et al., 2005; Zaromb & Roediger, 2010; Blanchette et al., 2018; Hong & Aqui, 2004]
6. POSITIVE emotions augment attention and increase flexibility; Negative emotions do just the opposite. Neurotransmitter chemicals are released when connections are made. Excitable moments in learning are remembered often!	Why? -Build a positive classroom environment centered around positive thoughts, positive literature, and mutual respect. Think about the last time you heard something negative, thought about something negative, and detected anger or fear. How did that make you feel? Help your students and help yourself. Incorporate "positive psychology" and kindness practices daily (see Seligman's pillars of positive psychology). [Hoehl et al., 2021; Nguyen et al., 2020; Seligman's positive psychology]

Neuroscience "Wisdom"	Application to Education
7. INTERPERSONAL NEURAL SYNCHRONY is real! Build relational dynamics between the brains and among the brains of people in the classroom. The more frequent the synchronization, the better the task outcomes. Incorporate best teaching practices to embed this task into daily interactions in a variety of settings. ENGAGEMENT that includes emotional content, is the driver of neural synchrony, constructing "sustained attention," event memory, and predicting events. Recess is not the only place for students to connect with one another!	Include, -Construct many opportunities to connect with your students and allow many opportunities for the students to connect with each other. - Set up learning stations, rearrange seating, foster kindness and develop games such as 'getting to know each other.' This builds agency, autonomy, "good citizenship", happier students, and more joyful teachers. Engaging topics and narratives that allow for turn taking promote learning and build healthy relationships in the classroom. [Markova et al., 2019; Hoehl et al., 2021; Nguyen et al., 2020; Bevilacqua et al., 2019; Atzaba-Poria, 2017; Koster et al., 2017, Song et al., 2021]

Table 19

Unpacking the Top 5 Neuromyths in the Field of Education

Neuromyth	Neuroscience	In Practice
1.Classify students based on their learning styles (i.e. visual learner, auditory learner, kinesthetic learner). The theory of "learning styles" lacks scientific evidence and has been proven false by neuroscientists. Over 90% of teachers believe it and many have received PD on it. This myth can be harmful to learning because it could limit teaching to	Learning processes are quite complex and classifying students based on their learning styles and matching them to teaching, scales down this process significantly. The process of learning incorporates seeing, hearing, doing, thinking, feeling, and being motivated to learn and form memories. It is quite complex. Experience is the signature in learning, meaning our daily interactions with each other, and the lessons presented in an exploratory fashion facilitate learning as neural networks are constructed. [Riener& Willingham, 2010; Newton, 2015; Dekker et al., 2012; Dandy & Bendersky, 2014; Geake, 2018]	Teachers can provide information in many ways so that students can have many opportunities to explore new concepts. However, the brain doesn't learn by matching teachers to student's learning styles. For example, if your student is a "visual learner" and they are trying to learn a second language, do the visuals help them to speak and pronounce words correctly? Learning is gradual and it takes practice, sometimes lots of it. How much time learning concepts takes depends on many factors such as the child's previous experience (background knowledge), their

Neuromyth	Neuroscience	In Practice
specific learning styles due to oversimplification.		ability, and their interest (motivation) in a given topic. VAKS/learning styles are false. Don't fall for them.
2. Left brain or right brain, and multiple intelligences... These theories can be misleading, leading to false assumptions and quite reducing to the complexity of the human brain and nervous system.	Brain neuroimaging has established that the left and the right hemispheres of the brain are consistently and continually communicating, despite the differences in their functions. Both hemispheres are responsible for most tasks and procedures. Our nearly 100 billion neurons and their trillions of connections span across the entire brain and communicate constantly with the nervous system. [Ansari, 2008; Geake, 2008 as cited by Torrijos-Muelas, 2021; Rousseau, 2021]	We use both sides of our brains and our many "intelligences" to execute the copious daily tasks and procedures in our lives. No one hemisphere and "intelligence" work in isolation. Foster students' interests and build new skills on their interests, skills, and strengths. Hyperfocusing on what they cannot do is unhealthy for child development, can make them feel bad about themselves, instills fear, and lowers their confidence level.
3. We use only 10% of our brains! This myth has survived for over a century. Wiliam James (1907) claimed that humans use less mental and physical resources than they can use, and in 1920, Einstein encouraged people to think more and to enhance their thinking, but he did not see the giant misunderstanding coming!	This neuromyth isn't even possible neuroanatomically. Neuroscience informs us the glia-neuron rate is 1:1 (in the past it was thought the ratio was 10:1, which may have perpetuated this myth). While brain imaging reveals areas of higher and lower activation on certain tasks, the process of thinking involves high levels of connectivity. Additionally, we are using all the areas of our brains even when we are sleeping, therefore this claim makes absolutely no sense. [Geake, 2008; Dunder & Gunduz, 2016; Papadatou-Pastou et al., 2017 as cited by Torrijos-Muelas, 2021]	With the many opportunities provided for teachers and students, it helps to know that we are using all the areas of our brains to interact with our inner and outer environments. Your students are consistently learning if you provide them with novel information, use different approaches, different contexts, and embrace the concept of interpersonal neural synchrony (see Figure 15).
4. Neuroplasticity is prevalent in the first 3 years of life/ "critical periods,"	Critical periods are certain times during a child's development when the brain is highly responsive to adjustments due to experience.	The ability to learn and make connections spans a lifetime. However, given what we know about child development so far

Neuromyth	Neuroscience	In Practice
and up to the age of puberty.	Neuroplasticity is substantially higher during critical periods. However, critical periods are influenced by factors such as the type of sensory input and the processes underlying the inputs. For this reason, most neuroscientists have switched to using the term “sensitive periods,” referring to the stage of development when neurons select from a wider spectrum of possible sensory inputs.	(more research is needed in this area), it is crucial to expose students to enriched environments throughout their development. Environments that are overstimulating are certainly not the same as enriched environments, which allow for age-appropriate exploration. A healthy learning environment is one that respects students’ learning processes and their development.
5.Multilingual myths: -Two languages compete for resources -Knowledge acquired in one language is inaccessible in another language. -The first language must be spoken well before introducing a second language. These myths were largely motivated by political factors and misinterpretations of prior studies.	-It is understood that our capacity to learn is not limited and the brain doesn’t get filled with one language. - Knowledge does not get stored in the form of different languages. For example, the storage may be transformed in the form of a picture or a sound, and even a smell. - Children who are bilingual tend to have a better understanding of languages overall. [OECD.org/education/ceri/neuromyth .htm]	- There is no problem if a child is open to learning multiple languages. - Knowledge can be accessed in any language at any time. - Bilingual or multilingual children can identify the structure of the different languages they know. However, it is important to note that while children learn languages quickly, if there is a language deficit detected (such as difficulties with a first language or sound differentiation), further assessment and intervention should be provided.

CHAPTER 5: DISCUSSION

This empirical study analyzed public school data from two large, diverse, urban districts by employing quantitative methods for analysis and using a neuroscience lens to help interpret the results through an integrative literature review. It further used neuroscience to provide more general guides to education with the goal of aligning education more explicitly with neuroscience and unpacking neuromyths, which are integrated together into a comprehensive framework (see Table 18 and Table 19). The collected data is representative of data commonly used in the Commonwealth of Massachusetts' public schools. Regression analysis of datasets was utilized to investigate relationships between performance-based and abilities-based assessments and gauge the predictability power between earlier and later performance scores across two academic years of 3^{rd} and 5^{th} grades, respectively. Performance of two subsets of students in terms of economic status and gender were further analyzed. Investigating emerging patterns over a 2-year time period in performance lends insight into the process of learning during specific developmental trajectories, offering predictability for future assessments and empowering educators with information needed to better prepare their students for academic success while helping them to build confidence and tenacity as they develop their skills. The findings from this examination were interpreted by exploring insights from neuroscience literature in an integrative review, offering educators a variety of ways to apply neuroscience in the classroom (see Table 18 and Table 19).

The data analysis in this study brought to light informative findings, which have been organized based on the constructed themes of each of the three questions.

Longitudinal Performance (Question 1)

This question examined earlier and later test performance-based and abilities-based scores in two districts in terms of their relationships and predictability. Several findings emerged from the acquired data analysis and my hypotheses for this question were supported. There is a significant correlation between earlier and later test scores (both on the MCAS tests and on the CogAT) in both districts A and B, demonstrating that earlier test scores in the 3rd grade can be used to predict future performance in the 5th grade. Both ELA and Math MCAS scores indicated a higher predictive power to the later MCAS scores than the CogAT scores. The high degree of observed correlation between the MCAS tests and the CogAT in both grades (3rd and 5th) within the two districts, lead me to think that Cognitive Abilities Tests or the CogAT batteries serve as performance-based assessments. While this instrument can be used to predict future performance in the primary grades, in light of using the MCAS (which is required by the state), it seems redundant to use and one may question its utility (refer to Appendix C).

As seen in Question 3 and in Table 18, from the purview of neuroscience, CogAT's marketing as an abilities-based test, testing reasoning ability, identifying student's "learning styles," and informing teachers to "tailor" lessons to match their student's "styles of learning," appears to be a neuromyth (Dandy & Bendersky, 2014; Dekker et al., 2012; Geaker, 2018; Riener & Willingham, 2010; Rousseau, 2021; Torrijos-Muelas, 2021). From the neuroscience perspective (Chapter 2- Deary, 2013; Deary et al., 2021; Deary et al., 2010; McFarland, 2017), mental abilities that are based on cognitive constructs developed in psychology relate to single or general abilities in a moment in time. The human brain and nervous system are much more complex and dynamic, and as a result there are lots of variability that contribute to performance at any given time.

Knowing that the MCAS or CogAT in the 3rd grade can be used to predict future performance in the 5th grade is powerful and can inform educators to set more specific benchmarks and provide the necessary interventions for their students to make academic gains. By understanding the relationship between the performance assessments, teachers can use either the CogAT or the MCAS tests in the 3rd grade to prepare their students for future performance in the 4th and the 5th grades. They can either construct preliminary tests aligned with the Common Core standards and the released test items from the prior 3rd grade's Next Generation MCAS tests or use the CogAT tests. In addition, students can be identified for advanced programming or gifted and talented screening, implementing enrichment that can be provided based on this authentic and comprehensive learning map.

Furthermore, in contrast to District A which screened students in the 3rd grade, District B reported administering the CogAT in the 2nd grade. Although the observed correlations between the 2nd grade tests and the 5th grade tests were reduced as compared to the 3rd grade and 5th grade tests, other districts might consider administering their screening in the 2nd grade to allow them an additional academic year for planning and more effective support.

Raw MCAS scores provide a measure of how a student performed in a particular academic year. After all, it was valuable to discover how much a student improved over time. According to the Department of Elementary and Secondary Education (DESE), this measure of growth can "provide evidence of improvement even among those with low achievement" and "gives high achieving students and schools something to strive for beyond proficiency." As part of this research, various factors of the available data were analyzed to find possible correlations to growth as defined by the Massachusetts Department of Elementary and Secondary Education (DESE). DESE defines growth as a measure of change in an individual student's performance over time. DESE explains that growth is calculated and expressed as a percentile which indicates how a student's "rate of change" compares to their academic peers, those who have a similar test score history. For example, the growth percentile would be 65 if a student improves by more than 65% of their academic peers.

This investigation demonstrated that neither earlier MCAS nor CogAT scores can have any predictive power on how a student might grow or decline in terms of their performance scores. The finding appears to connect with the neuroscience research on the non-linearity nature of the process of learning, and its conditional relationship based on genetics and environmental factors (Anderson et al., 2019; Anderson, 2014; Benoit & Gabola, 2021; Bevilacqua et al., 2019; Cozolino, 2014; Deary, 2013; Levitin, 2014; Lim et al., 2015). Further research needs to be constructed with a more keen focus on specific environmental factors that have predictive power on growth. Insights gained from this study can be incorporated and carried out further by school districts.

Examination of the Datasets (Question 2)

In Questions 2A- 2C analysis was conducted to examine differences between genders in terms of performance. In this section of data analysis that is only related to District A, my hypothesis was not supported as I did not expect to observe statistically significant differences between gender scores. The results, however, demonstrate some slight differences between genders in terms of their performance scores, which can have consequences if not taken into consideration. Based on neuroscience, the differences align with variation observed in the developmental trajectories of female and male students (see Question 3). Overall, the female students demonstrated statistical significance in their scores which were in the range of higher average scores for MCAS ELA in both grades 3 and 5 and in the CogAT verbal battery and male students scored slightly higher on the STE scores. There were no differences observed between genders in the average scores on the MCAS Math.

In the second part of Question 2, an examination was carried out to track overall performances differences between genders. According to Massachusetts Department of Elementary and Secondary Education (DESE), MCAS achievement results are divided into four categories: Exceeding/E expectations (student demonstrates an in-depth understanding and provides sophisticated solutions to complex problems), Meeting/M expectations (student demonstrates proficient understanding of subject matter and solves a variety of problems), Partially Meeting/ PM expectations (student demonstrates partial understanding of subject matter) and Not Meeting expectations/NM (Student demonstrates a minimal understanding of subject matter). The observed results demonstrate consistency with the findings of the first part of Question 2, in that overall female students' scores appeared in the higher achievement levels such as Exceeding/E and Meeting/M expectations. In contrast, a higher percentage of male students appeared in the not meeting/NM expectations category. In addition, it was observed that female students presented higher growth levels on both MCAS ELA and Math tests. Notably, female students began at higher scores on the MCAS ELA in the 3rd grade.

The results of this examination are closely aligned with marked findings in developmental neuroscience. It is noted that female brains during childhood generally develop slightly faster than male brains (Kolb as cited by Anderson, et al., 2019; Klingberg, 2013). Brain imaging such as MRI and fMRI indicate both increased structural connectivity in the parietal lobes and dendritic and grey matter volumes peaking in girls around the age of 10, whereas this growth is not apparent until roughly the age of 12 in boys (Anderson, et al., 2019; Klingberg, 2013). This is certainly not to assume that female students are more intelligent or learn faster, rather this observation is to point out the subtle differences in their development during the primary school years informing educators of differences in terms of learning, engagement, and behavior. For educators, it is important to know when we expect academic, emotional, and social milestones that are beyond children's developmental readiness, it can cause anxiety and behavioral ramifications that could be prevented with this knowledge. These observations indicate the need for further research on the neurological differences in genders in light of their developmental trajectories and their developmental readiness in school setting, as well as consideration on the crucial role environment plays in their growth and development.

While children grow and develop physically, cognitively, and emotionally at their own rates, this observed difference between genders speaks to the need for educators' awareness around these seemingly small developmental differences that could have a greater impact if the developmental milestones (between genders and individual cognitive differences) are not respected. All students, regardless of gender and other differences must be given a spectrum of opportunities for learning experiences and access to knowledge (section 1 of Chapter 2). Because experiences allow for learning to occur at the timing that is commensurate with a child's development, this is essential throughout the childhood years, especially during the sensitive stages of development (see Figure 14 and Figure 15). According to Klingberg (2013), we must remember that children's brains are not "mini" adult's brains. That different parts of the brain mature gradually and at the child's own pace. Unnecessary pressure beyond a child's development and conversely experiencing boredom can be emotionally detrimental and can lead to cognitive decline. This is especially important to consider when working with high IQ students who may face lack of balance or dyssynchronous development between their cognitive and emotional facets (Benony et al., 2007; Guenole et al., 2015) and whose developmental trajectories may be somewhat different from the norm (section 2 of Chapter 2, and Table 1). Employing strategies such as positive psychology, Cognitive Behavioral Therapy (CBT), and efforts towards establishing interpersonal neural synchrony are the most important steps in respecting the developmental trajectories in children (Anderson et al., 2019; Klingberg, 2013; Linden, 2018).

Questions 2D-2G examined scores pertaining to students who were identified as economically disadvantaged (EcoDis) as compared to the scores of students who were not economically disadvantaged (non-EcoDis). My hypothesis was supported in that the observed results demonstrated economically disadvantaged (EcoDis) students performed with lower scores across all performance tests, and they were observed to be behind across the two grade levels by about 10 points. There were no differences observed in growth as compared to the non-economically disadvantaged (non-EcoDis).

Neuroscience informs us of the importance of the environment and the major role it plays in terms of student's academic growth and emotional well-being. The results from this research are parallel to extensive neuroscience literature on this topic (Anderson et al., 2019; Ghazi et al., 2012; Kentner et al., 2019; Makharia et al., 2016; Reh et al., 2019; Taormina et al., 2013; see Chapter 2 of this paper). This data analysis examined different schools within each district. The growth percentiles for MCAS ELA and MCAS Math for the schools in both districts were analyzed. This analysis indicated that schools within a district had a consistent impact on student's academic growth. For example, school 54 in District A indicated a lower growth for both MCAS ELA and MCAS Math. Since multiple years of data is available, further study and investigation into the performance of each school within the districts is suggested to provide additional insight as to why these differences might exist.

As seen in Chapter two, the environment plays a crucial role in the cognitive and emotional developmental growth of children. The results for Question 2 are consistent with developmental neuroscience, neurobiology, neurophysiology, and neurocognitive psychology. The findings observed in this question with regards to gender differences in terms of test performance with the male students' lower test performance as compared to female students and the academic disadvantages that the subgroup of economically disadvantaged (EcoDis) students face indicates a discrepancy in the system for both groups. From the results, we learned the economically disadvantaged students appear to be academically disadvantaged as well. Students who are identified as economically disadvantaged (EcoDis) need much more emotional, academic, and social support and a more effective approach across all schools. The results from this question speak to the need for more serious prevention and intervention measures toward the academic success and emotional well-being of this particular group of students.

In working with economically disadvantaged (EcoDis) students, an overabundance of kindness, empathy, compassion, and mentorship is needed so that these students feel safe, have a sense of belonging, and can be motivated to go to school and succeed. Cognitive and social emotional support is needed across the grade levels in order to assist the students in their learning and achieving progress. "Anxious cognition" gets in the way of attention, memory and learning, and can lead to negative cognitive biases as children grow (Hoffman, et al., 2012; see Figure 27).

By incorporating the findings of interpersonal neural synchrony (section 1 of Chapter 2), teachers can play a significant role in the lives of the economically disadvantaged (EcoDis) students (see Figure 15). Bevilacqua et al. (2019), found that social closeness between students and teachers raised the level of brain-to-brain synchrony and the retention of content. Social factors such as empathy and affinity with community members can make a significant difference.

Higher neural synchrony and higher reciprocity have been found correlated (Lumsden et al., 2014). It takes patience, collaboration, effort and the willingness to understand what is needed to help the students who are economically disadvantaged. Their developmental trajectories and mental status must be carefully monitored and assessed before effective interventions are developed and prescribed. In addition, patterns in behavior must be closely examined before disciplinary consequences are carried out.

In the case of gender differences, the results conveyed that male students may be academically hindered in the primary grades with more of them in the NM (not meeting) and less of them in the E (exceeding) category. In other words, there appears to be discrepancies within the school systems based on both gender and socioeconomic status. From neuroscience research (see Chapter 2 and Table 18), some classroom strategies are offered that would address these inconsistencies within the system. The results inform us of the importance of the timing of assessment for different students, their developmental consideration, how content is presented, and how to best approach these students with a more comprehensive and well-informed pedagogy that targets their learning based on their developmental, academic, and emotional readiness. While for this research additional data such as the home environment and family structure were not obtained, they would add value to future research.

Neuroscience and Education (Question 3)

Question 3 aimed to connect neuroscience research to findings observed in the results of Questions 1 and 2. Using a neuroscience lens, it was demonstrated that there are issues that appeared to be related to neuroscience which were plausibly measurable using the MCAS and CogAT test instruments. Specifically, as seen in Table 18, there are recent findings in neuroscience that are meaningful, relevant, and applicable to the classroom. The field of neuroscience is expanding continually, and new findings are emerging virtually every day. It would serve us well to incorporate the current findings into a structure that is much needed in the field of education across all grade levels, while remaining cognizant of the novel and emerging findings, and questioning how these findings apply in the educational context. I assert this cycle must be repeated in order to be effective. For this reason, it is incumbent upon neuroscientists to translate their newfound knowledge into a language that is comprehensible by educators, thereby constructing a perpetual connective tissue between the two fields. Flexibility, continuous research, and objectivity are pivotal to constructing and preserving a neuroscience-informed educational system. In my opinion, striving to eliminate counterproductive and incompetent neuromyths is the very first step to thinking more objectively and critically (Levitin, 2014). The function of the human brain is dynamic, depending on a myriad of factors, emphasizing the phenomena taking place internally when external interpretations and perceptions are made (Buzsaki, 2019; DeSalle, 2019).

Overall, this research shows that existing performance data acquired from public schools can serve as a useful tool to map several cognitive dimensions in a comprehensive, scalable, manageable, affordable, and effective manner. Table 18 was created to emphasize the seven most relevant insights from the field of neuroscience connected to daily teaching strategies that can be utilized in the classroom.

The table below displays a summary of the process of analysis, results, and neuroscience interpretation as applied to education.

Table 20

Summary of Results, Neuroscience Relevance, and Educational Implications

Question	Results	Neuroscience Interpretation & Newly informed & Neuromyth -Free Implications in Education
Question 1 Longitudinal performance: track students across time to determine the correlation between earlier and later test scores and growth.	*Initially utilized scatterplots to see relationships and then employed linear regression, which provided a mathematical and quantitative measure of the relationships*	- Both MCAS and CogAT tests measure performance. - The CogAT's suggestion that testing for "learning styles" and preparing teachers with individual student's "learning profiles" is considered a neuromyth, and maybe redundant in light of using the MCAS tests. As seen in Table 19: *Unpacking the Top 5 Neuromyths in the Field of Education,* the theory of "learning styles" lacks scientific evidence and has been proven false by neuroscience (Dandy & Bendersky, 2014; Dekker et al., 2012; Geaker, 2018; Riener & Willingham, 2010; Rousseau, 2021; and Torrijos-Muelas, 2021).
1A-What is the relationship between earlier test scores and later test scores? Hypothesis: Supported.	-High degree of correlation was observed between the scores. -High degree of correlation between later and earlier scores was observed. The earlier scores can be used in predicting future MCAS scores based on 3^{rd} grade MCAS and CogAT scores. -Some scores have a greater impact on predicting than others. i.e. CogAT V has a greater effect on 3^{rd} grade MCAS ELA vs. CogAT Nonverbal on 3^{rd} grade MCAS ELA.	- Neuroscience findings reveal that learning, an extremely complex process that is highly individualized, involves many interactions including abilities based on genetics and environmental factors (Section 2 of Chapter 2), engagement during tasks, emotions, interpersonal synchrony, teacher likability, pedagogy, attention based on content interest (Section 1 of Chapter 2), and first and foremost feeling safe and free from fear and anxiety (Section 3 of Chapter 2). - Performance can be predicted based on metrics using a spectrum of formative and summative assessments available to educators, to inform them of the need of mediation when necessary and utilizing preventive and intervention strategies to improve their students' future performance. - To boost student performance, confidence, feelings of attainment and achievement and well-being, student preparation is absolutely necessary. - Repeated experience and association strengthen neural connections, increases processing efficiency, and can lead to dopamine release in neurons gradually firing when stimulus (content) is novel and exciting and there is a reward in applying intentional attention, demonstrating that neurons can eventually predict the reward followed by stimulus.
1B-What is the relationship between earlier test scores and growth as measured in the 5^{th} grade MCAS?	-No high degree of correlation is observed. -Growth cannot be measured using these assessment tools.	- As seen in Table 18: *Neuroscience "Wisdom" and Application to Education*, student success is based upon incorporating consistent preparation methodologies based on formative and summative assessments to inform teachers' planning, facilitating engagement in learning, providing many opportunities for learning novel content and connecting the knowledge to prior content. - Excitement in presenting topics, repeating information in a variety of ways and as needed, routinely teaching study skills while being cognizant of individual students' developmental milestone, being patient and allowing space between lessons, and most importantly relating to students with positive emotions, which augment attention and increase flexibility in

Question	Results	Neuroscience Interpretation & Newly informed & Neuromyth -Free Implications in Education
		learning (Blanchette et al., 2018; Callan & Schweighofer, 2010; Hong & Aqui, 2004; Jasanoff, 2018; Kania et al., 2005; Renee van Kesteren & Meetrer, 2020; Rossi et al., 2015; Zaromb & Roediger, 2010).
Question 2 Examining distribution of nonquantitative data: gender and EcoDis 2A-Gender Hypothesis: not supported. 2B: Gender %ages on MCAS Hypothesis: supported. 2C: Gender & MCAS growth	*ANOVA Test for Gender Differences was conducted with a 5% confidence level.* Female students scored higher in CogAT V, 3rd & 5th MCAS ELA Male students scored higher on CogAT Q. No sig. differences in CogAT NV, MCAS M & slightly higher on STE performances. -Higher %age of F exceeding and a lower % F in the NM. Higher %age M exceeding in 3rd & 5th Math; higher %age in NM. %age of F in the NM < M across the five performance Assessments. -F display higher growth in both MCAS ELA and M. They began higher on the MCAS ELA in 3rd.	On gender differences, - Neuroscience informs that the timing of development in children is nonlinear and varies based on many factors, one of which is gender. - Zayed and Jansen (2018) found small gender differences, where girls performed higher in one of the working memory tests, and boys demonstrated higher performance in the coordination motor test. In addition, significant correlation was observed between math and science performance and coordination in motor tasks. - While children grow and develop physically, cognitively, and emotionally at their own rates, this observed difference between genders speaks to the need for educators to be aware and cognizant of these seemingly small developmental differences that could have a greater impact if the developmental milestones (between genders and individual cognitive differences) are not respected. - All students, regardless of gender and other differences must be given a spectrum of opportunities for learning experiences (Section 1 of Chapter 2). Because experiences allow for learning to occur at the time that is commensurate with a child's development, and this is essential throughout the childhood years especially during the sensitive stages of development (Chapter 2). - Unnecessary and untimely pressure beyond a child's development and conversely experiencing boredom can be emotionally detrimental and can lead to cognitive decline. This is especially important to consider when working with high IQ students whose developmental trajectories may be different from the norm (Section 2 of Chapter 2). - Employing strategies such as positive psychology and Cognitive Behavioral Therapy (CBT) and efforts towards establishing interpersonal neural synchrony are the most important steps in respecting the developmental trajectories in children (Anderson et al., 2019; Klingberg, 2013; and Linden, 2018).
2D:EcoDis vs. Non EcoDis Hypothesis: supported.	*ANOVA Test for Economic Performance Diff. Table 18. 571 EcoDis vs. 382 non EcoDis* -EcoDis performed lower across all tests, with a wider gap observed in the	- Meeting the needs of this group of students and providing effective interventions has been at the forefront of concerns in the field of education and our society at large. - Neuroscience informs us of the importance of early and continued enrichment, reducing toxic factors from the environment, and most importantly establishing attachment during the early years of development (Cozolino, 2014). - Jasanoff (2018) writes about the importance of the environment and the brain, an organ inseparable from the

Question	Results	Neuroscience Interpretation & Newly informed & Neuromyth -Free Implications in Education
2E.%age of EcoDis NM MCAS, PM, M, E Hypothesis: supported. 2F. Differences in MCAS growth-EcoDis vs non-Eco-Dis 2G. growth %ile in districts	5th grade, barely above PM range of 470-499 -In E, similar between two groups In M, EcoDis is 10 points lower than non EcoDis. -In PM, similar, and about 10 points higher. -E similar * a higher %age of EcoDis are in the lower achievement groups. -Longitudinal examination reveals a wider gap in E (0.35% E EcoDis vs. 3.1% E non EcoDis) *ANOVA was performed* -No differences in terms of growth. -Again, growth is not measured. *SGP=how each student is achieving relative to state stds* 40-60 growth percentiles. Performance in different schools vary in each District And warrant a longitudinal test.	body and the environment. Brain, body and environment are tightly connected and interwoven, and if neuroscience is to make a change, a more individualized approach is needed. - Ghazi et al., (2012) conducted a cross-sectional examination of 529 students in Iraq, the results of which found a decline of IQ in children associated with the lack of feeling safe, mental stress, and living in a toxic environment. - Makharia, et al., (2016) found that environmental factors such as neighborhoods, physical activity, family, income, parental occupation, education, and socioeconomic status played a profound role on the IQ the children displayed. - According to Maslow's theory of motivation, children cannot display the motivation to learn if their basic physiological needs, safety, and belonging have not been met. - Cozolino (2014) and Gee & Casey (2015), found positive attachment schemas form throughout childhood (Section 1 of Chapter 2), in particular during the sensitive periods of development. - Suskind and Denworth (2022) insist on taking vital measures in early childhood for later success in school. They contend that above all else, children need two fundamental things to be successful: nurturing interactions with those around them and safety from "toxic stress" from the environment. - In working with economically disadvantaged students, kindness, persuasion and empathy are crucial to making them feel safe, experience a sense of belonging, and demonstrate motivation to go to school and succeed. Cognitive and social emotional support is needed across the grade levels in order to learn and achieve. "Anxious cognition" gets in the way of attention, memory, and learning, and can lead to negative cognitive biases as children grow (Hoffman, et al., 2012; Figures 20, 21, 22, 23). - By incorporating the findings of interpersonal neural synchrony (Section 1 of Chapter 2), teachers can play a significant role in the lives of the economically disadvantaged students. - Bevilacqua et al. (2019), found that social closeness between students and teachers raised the level of brain-to-brain synchrony and content retention. Social factors such as empathy and affinity with community members can make a difference and higher neural synchrony and higher reciprocity are correlated (Lumsden et al., 2014). - It takes patience, collaboration, effort and the willingness to understand what is needed to help these students. Their developmental trajectory and mental status must be carefully assessed before effective interventions are put into place. - In addition, patterns in behavior must be closely examined before disciplinary consequences are carried out.

The insights from the captivating concept of interpersonal-neural synchrony (see Chapter 2) are at the forefront of neuroscience research and can be practiced in classrooms and homes. We live in an age when due to societal demands parents tend to be distracted, family structure and value systems seem to have shifted, and our first priorities, our children, are being compromised as a result. We are observing the negative effects of these changes on our students and in our society (CDC, n.d.; OECD, n.d.; Prinstein & Ethier, 2022; Suskind & Denworth, 2022). While the discovery is young, the concept of interpersonal neural synchrony is quite promising, inviting parents and teachers to provide quality interactions and attention to children that has been proven to be effective for both children and adults across cultures and time.

In terms of learning, neuroscience informs that neuronal oscillations interact at different frequency bands and tend to modulate each other to display specific behaviors. Different oscillation activities may compete or cooperate in such a way that allows for connecting neurons into ensembles and thereby facilitate synaptic plasticity. Research scientists have uncovered that optimization of rhythmic stimuli or interaction due to high neural excitability leads to processing enhancement. Bevilacqua and team (2019) demonstrated the importance of understanding neural mechanisms in predicting academic performance, identifying a strong connection between attention, interpretation, and retention related to stimulus (content), and concluding that student to teacher closeness tends to lead to brain-brain synchrony. Interpersonal neural synchronization between speaker and listener demonstrates association with greater transfer of information and mutual understanding between them when behaviors were aligned. Neurophysiological processes are formed based upon the relationships we construct (Hoehl, 2021).

Interpersonal neural synchrony research indicated there were no observed neural synchrony between stranger-child cooperation, suggesting that interpersonal neural synchrony is basically dependent upon relationships that have been constructed (Lumsden et al., 2014). Higher neural synchrony and higher behavioral reciprocity are correlated (see Figure 13, Nguyen et al., 2020a, b, and c). The social benefits to interpersonal neural synchrony range from affording predictability to joint attention and action, exchange of information, and a social "adhesive" for affection and belonging (Lumsden et al., 2014).

Case studies in support of interpersonal neural synchrony (Chapter 2) exhibited the essential role of mothers, fathers, and teachers in children's lives. Maternal sensitivity is crucial in establishing neural synchrony. Reciprocal manner in interactions between mother and child indicated better alignment to social and cognitive development (Markova, 2019; Nguyen 2020). Children's cognitive development in their father's presence has been linked to better development in problem solving skills and higher levels of competence. Fathers played a central role during problem solving tasks when children gained social confidence, agency, and communication skills. The findings speak to the crucial role fathers play in healthy child development. While our current state of education is not aligned to this new science of brain research, the few case studies in the classroom indicated empathetic disposition was so powerful that it made up for the absence of other factors in terms of interactions (Dikker et al., 2017; Figure 15). More extensive research on interpersonal neural synchrony in the classroom is in progress.

Limitations and Future Research

The focus of this study was to shine the light of neuroscience on the results of quantitative data analysis that emerged from the furnished data from two large, diverse, urban districts. With this empirical approach, longitudinal performance (Question 1) across two grade levels was analyzed, identifying the value of performance assessment beyond their current use in public schools, questioning the utility of the CogAT given its described relation to neuromyths from the purview of neuroscience, and recognizing the need for further research on specific environmental factors inquiring whether or not they would provide predictive power on growth.

Question 2 identified two types of disparities based on the provided data from one of the districts (District A): Differences in performance scores in terms of genders (reported female and male) and differences in performance of economically disadvantaged students as compared to the non-economically disadvantaged students (reported EcoDis and non-EcoDis). In this question, the study lacked information about environmental factors such as teacher information, enrichment groupings, and intervention programs, family structure, dynamics and supports, and parent or guardian's level of education. Both types of disparities (gender and economic status) highlight the importance of understanding the unique developmental trajectories in children and providing pertinent support that commensurate with the students' natural development. This is especially crucial during the sensitive periods of development that may differ from neurotypical expectations.

While in this examination, the disparities that were identified focused on gender differences and economically disadvantaged students, these insights are not limited solely to these two populations. As an example, in chapter 2, I discuss the high IQ population of students in-depth. While the furnished data for this study did not include identified groups of high IQ students due to the lack of reliable and valid IQ testing and available scores, this extensive and broad, international research of the high IQ population using an objective lens is contributed to Chapter 2 of this dissertation.

As an active practitioner in the field of advanced learners (G & T), I highly recommend reflecting on the literature that is contributed to Chapter 2 and being selective in choosing literature that is related to the high IQ population. Choosing brain-based and current peer-reviewed scientific literature, staying away from dated literature and eminent systems that tend to divide people instead of uniting them, and exploring studies that are based on meta-analysis and longitudinal research, affords a critical lens in terms of inquiry and in creating authentic measures to meeting the academic and social emotional needs of high IQ students. In the field of gifted and talented education we tend to rely heavily on subjective, dated, and anecdotal recommendations that lack objectivity and contain numerous neuromyths which proliferate with time. Much further and extensive empirical, longitudinal studies, meta-analytical investigations, and peer reviewed research are needed in this area (Calero et al., 2007; Eren et al. 2018; Karpinski et al., 2018; Martin et al., 2009, 2010; Morawska & Sanders, 2008; Subotnik et al., 2011; Suldo et al., 2018; Vaivre-Douret, 2011).

Final Reflection

The intriguing and complex process of learning requires plasticity of the neural connections in the brain through the brain-body connection and interactions with the environment. Learning and constructing memories depend upon how efficiently neurons transmit messages and pass along information to other neurons through synapses, lighting up the learning paths. A few scientific insights that can be deduced from this research include encoding and retrieving information, which are the two facets of memory that can be impacted by factors such as development, stress, gender, and socioeconomic differences (as seen in the results of Question 2), associating new memories with older recollections supports encoding (as seen in Question 1). Therefore, practice and repetition improve performance and build confidence. Findings such as these can inform educational practices, improve students' academic performance, and support their social-emotional growth.

We live in an age when neuroscientists are now able to compare the action potential's rate of firing neurons to behavioral and performance tasks (Jasanoff, 2018). Understanding the structure and the function of neural circuitry and the phenomena of learning must serve as the building blocks of schooling, setting the primary tone and structure for our educational system. As seen in Question 3, learning involves emotions as well as rich, stimulating environments that provide students ample opportunities for exploration, which are crucial to healthy cognitive, emotional, and social child development (Blanchette et al., 2018; Callan & Schweighofer, 2010; Kania et al., 2005; Klingberg, 2013; Rossi et al., 2015; Zaromb & Roediger, 2010). Due to the dynamic functionality of our neuronal structures, children's behaviors and mindsets can vary at any given point in time. Behaviors can shift based on the characteristics and mindset of children and the environments to which they are exposed. Neuroscience insights such as these brighten unseen pathways to solutions relevant to teaching and learning (see Table 18). Teachers, administrators, school adjustment counselors- all educators and stakeholders working with students would immensely benefit from neuroscience education towards making a positive impact on their students' learning, emotional, and educational experience.

In 2018 researchers (Romeo et al. 2018, as cited in Suskind & Denworth, 2022) examined the structure and function of 4–6-year old's brains in a brain scanner while they were told stories about pleasant scenes of opening birthday presents and playing hide and seek. The recordings of the two days noted the importance of reciprocity in language development where more activation was observed in the key language regions of the brain in the children who were engaged in reciprocal interactions in a positive setting. The idea of reciprocity is associated with the concept of interpersonal neural synchrony. The latest brain research contends the missing link in engagement and performance may be the relational dynamics of the brain between and among people in the classroom, an occurrence called interpersonal neural synchrony (Djalovski et al. 2021). The exploration of how inter-brain synchrony occurs at the neuronal level, how the identified brainwaves demonstrate that behaviors are aligned, and that our neurophysiological processes are formed based upon our relationships, inform solutions to the typical uncertainties we often encounter in the field of education.

Like the individual neurons seeking to connect, I declare that in service of our children, we must join brains and hearts, in order to ensure their healthy developmental, cognitive, social, and emotional growth. Their well-being rests upon our due diligence and efforts to keep them safe from negative stimuli, to guard them from toxic ideas, and to protect them from unnecessary fear and stress that can lead to anxiety and other mental health problems. From Levitin I learned that in thinking critically, completely, and creatively, we keep what we have learned if the claim is proven by logical evidence and we lose misinformation that proliferates if not prevented (Levitin, 2016). During this informational age, we must strive to teach our children to be objective and think critically so that they can develop discretion and distinguish the credible from the implausible (Levitin, 2014). Are we all capable of modeling this construct for the citizens of the next generation?

Ehrlich (2022) tracked Cajal’s use of the word “connection” in 45 different papers, and Levitin (2016) calculated the formula for how many ways neurons can be connected to each other. According to his calculations, for 3, there are 8, for 4 there are 64, for 5, 1024, and for 6, 32768 possibilities. Our brain cells, tissues, and organs form a unified being with parts that are not separate from the whole. This is closely akin to the great classical Persian poet Saadi ’s enlightening poem when he modestly writes, "Human beings are members of a whole, in creation of one essence and soul. If one member is afflicted with pain, other members uneasy will remain. If you have no sympathy for human pain, the name of human you cannot retain." The evocative words of a humane poet illuminate the page and the mind alike, inspiring me to wonder about how many ways we humans can connect for the better good, in service of our children, and united as parts of a whole. With the knowledge of neuroscience lighting the way and guiding us, we must work together, be positive and empathetic while staying objective in constructing neuromyth-free solutions that lead to prudent and thoughtful decisions in support of all students.

Cajal (as cited in Ehrlich, 2022) believed his laboratory served as an "academy of anatomy." By analogy, I affirm schools ought to be "academies for children." In these academies, teachers and administrators will be in tune and in sync with children through their pedagogy, curriculum, class and school structure based on the pillars of neuroscience and wisdoms of education, thereby establishing interpersonal neural synchrony. Children are individual units, brains and bodies functioning to learn from their environment and to build bonds with those who are fortunate to surround them. At these "academies for children" authentic knowledge is celebrated and shared, and every child can access knowledge at their own special "right time," where they learn academics, are given opportunities to be kind and give back; the hallmarks of a "good citizen."

Cajal (as cited in Ehrlich, 2022) found neural communication occurs across the synaptic gap, ending of axons and beginning of dendrites "well suited" for each other. Likewise, interpersonal neural synchrony and brainwaves in sync reveal that communication between people requires the brainwaves to be in synchrony. Lagging brainwaves and those out of synchrony inhibit proper communication. In service of our children, we must consider the cognitive as well as the emotional aspects of learning and create methods designed to fit children's natural functions and support their natural and healthy growth.

In designing this examination, in many ways I strived to maintain my work in accordance with Cajal, Levitin, and Klingberg (2013) in adhering to thinking objectivity and scientifically, embracing Klingberg's idea that if future research is shaped by neuroscience in collaboration with experimental psychology, cognitive neuroscience, and pedagogy through the instrument of scientific method and selection of randomized studies, then we are on our way to finding light. There is light if we strive to identify the mechanisms behind perpetual issues that impede healthy child development and even prevent them. Indeed, a higher magnification into our schools and daily interactions of students is crucial in developing informed decisions aligned with their natural development, wellbeing, and happiness.

In this study it has been demonstrated that performance assessments and analysis of datasets can inform well beyond simply utilizing them to reach proficiency levels. In addition, employing the new technology of hyperscanning can reveal the constitution and dynamics of the brain's internal workings. Each brain wave or oscillation has a unique amplitude and frequency and is therefore measurable. Quantitative data analysis allows us the potential to interpret them in more objective and meaningful ways as related to the phenomenon of learning. While the road ahead may be winding, blurry, and even dark at times, we are profoundly fortunate to have access to the novel and growing knowledge of neuroscience, the light which essentially applies to education and illuminates hidden neural paths that if recognized, will gradually lead us to helping our students thrive cognitively, emotionally, and socially.

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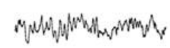
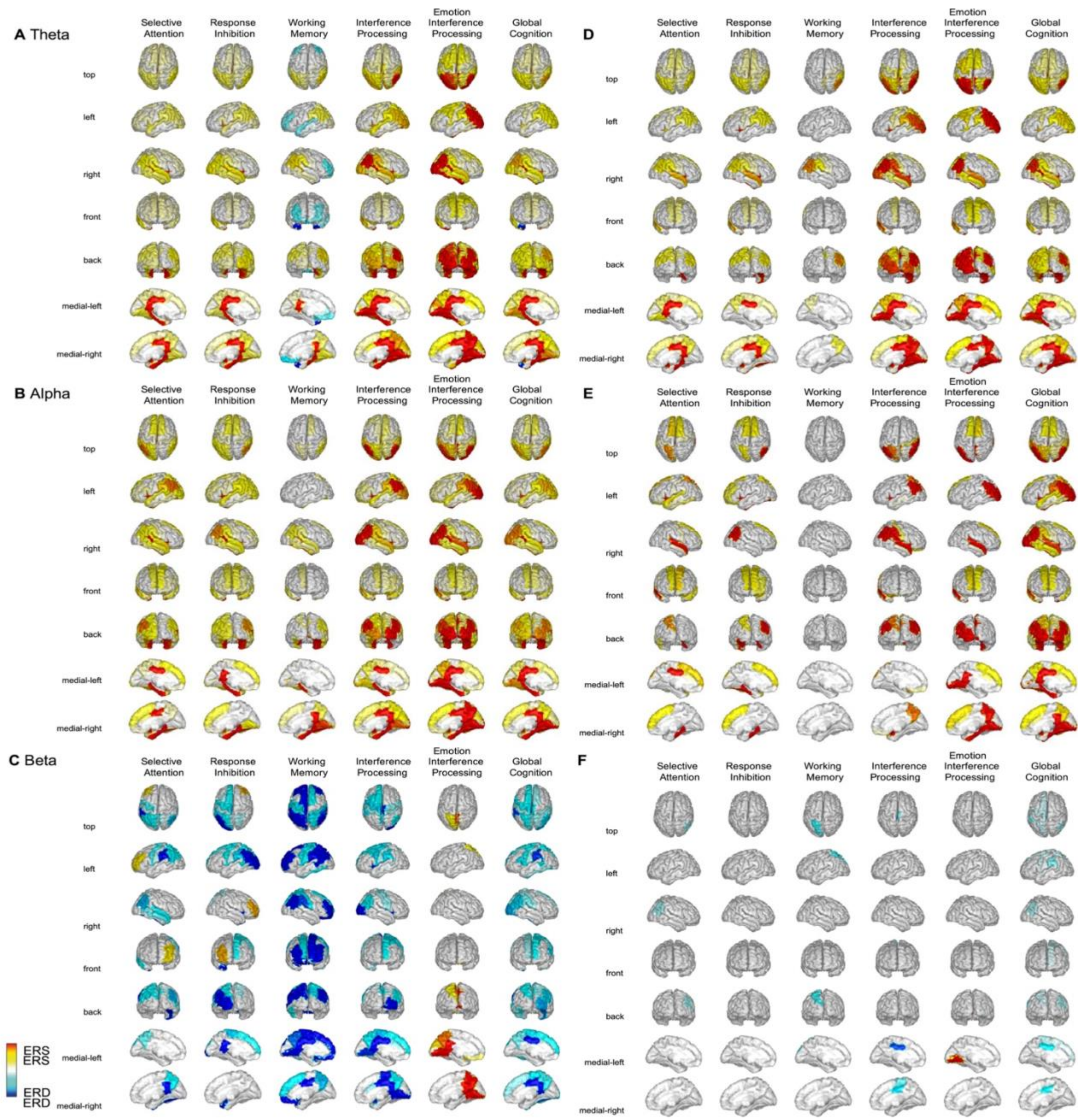
Appendix A

Band	Delta – δ	Theta – θ	Alpha – α	Beta – β	Gamma – γ
Frequency	1–4 Hz	4–10 Hz	8–12 Hz	12–30 Hz	>30 Hz
EEG traces					
Brain area	Neocortex, Thalamus, Basal ganglia	Hippocampus, Dentate gyrus, Cortex, Amygdala	Neocortex, Thalamus	Neocortex, Olfactory bulb, Striatum, Thalamus Hippocampus	Neocortex, Olfactory bulb, Hippocampus
Brain functions	(a) Slow wave sleep and deep NREM sleep (b) Signal detection and decision making (c) Memory consolidation (d) Concentration, motivation and focused attention (e) Facilitation of interlaminar interactions in the cortex to control synaptic rescaling	(a) REM sleep (b) Selective attention, arousal, orienting, and voluntary control of movement (c) Modulation of synaptic strength and coordination of phase coding of active neuronal ensembles (d) Episodic memory, word integration and environmental encoding	(a) Drowsiness and relaxation (b) Sensory function, movement and visual perceptual framing (c) Task engagement, speed of working memory and cognitive performance	(a) Sensorimotor control, motor preparation. (b) Sensory processing-amplification of olfactory and visual stimuli (c) Top-down attention and working memory allocation	(a) Focused attention and motor task execution (b) Responses to evoked auditory and visual stimuli (c) Facilitation of neuronal communication and efficient cognitive processing (d) Spatial working and recognition memory
Rhythm generators	(1) Interplay between low threshold Ca^{2+} transient current and hyperpolarization activated cation current (McCormick and Pape, 1990; Soltesz et al., 1991) (2) NMDAR-driven depolarization of intrinsically bursting neurons (Connors et al., 1982; Carracedo et al., 2013; Steriade et al., 2018) (3) Neuron-glia interactions to regulate extracellular K^+ through Ca^{2+} waves (Amzica et al., 1997, 2002; Kozachkov and Michmizos, 2017)	(1) Interplay between inhibitory and excitatory hippocampal neurons that is modulated by cholinergic and GABAergic input from the medial septum (Freund and Antal, 1988; Buzsáki, 2002; Hangya et al., 2009) (2) Interplay between slow inward K^+ currents and persistent Na^+ current (D'Angelo et al., 2001) (3) ACh-mediated Ca^{2+} release from astrocytic internal stores (Foley et al., 2017) (4) Neuromodulation of the prefrontal cortex by Dopamine (Eckart et al., 2016)	(1) Cholinergic modulation of the prefrontal cortex (Dipoppa and Gutkin, 2013) (2) Activation of mGluR1 in the GJ connected high-threshold bursting neurons in the lateral geniculate nucleus (Hughes et al., 2004, 2011) (3) Activation of the noradrenergic neurons in the locus ceruleus, mediated by Corticotropin releasing hormone (McCormick, 1992; Jedema, 2004; Enoch et al., 2008)	(1) Activation of gap junction-coupled layer V neurons, mediated by the M-type K^+ current (Roopun et al., 2006) (2) ACh modulation of synaptic interactions between layer V pyramidal neurons and low-threshold spiking interneurons (Roopun et al., 2010)	(1) Tonic activation of interneurons by mGluR (Whittington et al., 1995) (2) Cholinergic modulation of pyramidal neurons (Fisahn et al., 1998) (3) Modulation of interneurons via gap junctions; activation of inhibitory interlaminar connections (Ainsworth et al., 2011) (4) Ca^{2+} – dependent glutamate release from astrocytes (Lee et al., 2014) (5) Increase in $[K^+]_o$ enhance activation of fast inhibitory and excitatory networks (Traub et al., 2001; LeBeau et al., 2002)

Note. Brainwaves from

https://www.frontiersin.org/articles/10.3389/fnins.2019.01125/full

Appendix B



Note. Cognitive Maps from

https://doi.org/10.1016/j.neuroimage.2020.117641

Appendix C

Next Generation Massachusetts Comprehensive Assessment System, MCAS (ELA, Math, STE)

History, Validity, and Reliability

In 2016 (and prior to 2016), the old Massachusetts Comprehensive Assessment System/MCAS or Legacy MCAS was used. At that time, MCAS was used mostly by urban districts while the schools in the suburbs used the Partnership for Assessment of Readiness for College and Careers/PARCC. Launched in 2017, The Next Generation Massachusetts Comprehensive Assessment System/MCAS is the new and improved MCAS that is currently in use. MCAS is a summative assessment used in all the public schools in the Commonwealth, grade 3-8 and 10, measuring students' mastery of the Massachusetts Curriculum Frameworks and serving as a graduation requirement. There are extensive documented details about the process used to develop, administer, score, and provide reports of the results of the MCAS. According to the Department of Elementary and Secondary Education/DESE, the new MCAS is much more comprehensive and thought out, using a new and much improved scale. The percentile scores were constructed from quantile regression analysis, a 3D, aggregated regression model that measures growth in percentiles (per DESE).

Scoring

As a feature of this test, all scores are scaled to a range of 440 to 560 points, with nominal grade-level mean score of 500 points and standard deviation of 20 points. The range is divided into four achievement levels, each spanning 30 points as indicated in Table 7.

Process

The questions on The Next Generation MCAS were proposed by two contractors: Pearson and Incognia. They were then reviewed by the "content and bias and sensitivity" committees composed of educators and experts in teaching their academic disciplines. Revisions were suggested before moving the questions to DESE's test developers and editorial staff before being field-tested (questions that are field-tested do not count towards scores of participating students). Using statistical data, the "content and bias and sensitivity" committee reviews again and content experts in higher education check for accuracy. If accepted, the questions move to a "common pool" from which the MCAS questions are selected. Student scores are based on the questions from the "common pool." The process is comprehensive, rigorous, detailed, well thought-out and well-reviewed. Every effort is made to ensure the content is equitable, fair, and aligned with the Common Core Standards. There are several systems/committees of checks and balances, as well as independent institutions (Pearson and Cognia) to ensure integrity and excellence in choosing the content questions. The information furnished here was obtained from the DOE resource links, the schematic listed in Appendix C, and from a direct interview with DESE.

Description of Assessment

According to the Department of Elementary and Secondary Education/DESE, the 2017 grades 3 and 5 Next Generation MCAS ELA assessment were made up of three sessions, reading, writing, and language. Each session included reading passages, selected response questions, and essay questions. ELA test results are reported under three MCAS reporting categories. During all three ELA test sessions, the use of bilingual word-word dictionaries was allowed for current and former ELL students. No other reference materials were permitted.

Administered in two sessions, grades 3 and 5 Next Generation MCAS Mathematics tests were based on standards in the five domains in the *Massachusetts Curriculum Framework for Mathematics.* These included operations and algebraic thinking, number and operations in base ten, number and operations-fractions, measurement and data, and geometry. Each session included selected-response, short answer, and constructed -response questions. Test results were reported under five MCAS reporting categories that were identical to the framework domains. Each participating student was provided with a plastic ruler. During both sessions, the use of bilingual word-word dictionaries was allowed for ELL students. No calculators were allowed.

The 5^{th} grade Next Generation MCAS STE test was made up of two test sessions, each of which included selected-response questions and constructed-response questions. The STE test was based on learning standards in the four major content strands in the April 2016 *Massachusetts Science and Technology/Engineering Curriculum Framework.* The strands included Earth and space science, life science (biology), physical sciences (chemistry and physics) and technology/engineering. The use of bilingual word-word dictionaries were allowed for ELL students.

Cognitive Abilities Test, CogAt (verbal, quantitative, nonverbal)

History

The CogAT Forms 7 and 8 (the latest version, Form 7 was used prior to Form 8) were developed by David F. Lohman (professor of educational psychology at the University of Iowa and the co-author of CogAT Form 8) and Joni Lakin (associate professor of educational research, University of Alabama, co-author of Form 8 CogAT and affiliated with the gifted education office at UA). Joni Lakin studied with David Lohman in the Educational Psychology program at the University of Iowa. According to Riverside Insights, the publishing company of the CogAT, equitable assessments help teachers to develop “tailored-instruction” for their student’s “learning styles” and “abilities.” The test is advertised as the “most chosen ability assessment for educators.” More recently (April 2022), Riverside Insights partnered with Renzulli Learning-Total Talent Development, an online enrichment system promising a “whole learning approach,” a derivative of University of Connecticut’s Renzulli Center for Creativity, Gifted Education and Talent Development. The leading G&T organization in the Northeast is based on Joseph Renzulli’s (educational psychologist on the board of UConn’s Neag School of Education) three Ring Conception of Giftedness or triad model for curriculum compacting and differentiation.

Process and scoring

The CogAT Form 8 comes with 3 different batteries of summative assessments to measure “ability,” as defined in educational psychology, and is generally used by some schools (that offer programs) as a universal screener for advanced or G/T programs. The summative assessments can be administered in grades K-12. The three batteries of CogAt Forms 7&8 include verbal, quantitative, and nonverbal reasoning or pictorial sections. The levels of scores are representative of student’s stanine on the three sections of the CogAT. The age stanine score range is from 1-9, 9 as the highest. In the CogAT, a higher stanine is indicative of higher cognitive ability, while a lower score indicates lower cognitive ability. A stanine of 5 indicates placement in the 40^{th}-59^{th} percentile or average cognitive ability. Standard Age Score (SAS) is a normalized Standard-Age score of a mean of 100, and a maximum score of 160 (Standard Age Scores 89-111 are in the average range).

WIDA ACCESS English Language Learners (ELL)

History

ACCESS is a summative English language proficiency assessment taken annually by English Language Learners (ELL) in K-grade 12. According to DESE, Federal and state laws require annual assessments of ELL students, measuring their proficiency in listening, writing, reading, and speaking. In addition, the progress of ELLs is measured annually. ACCESS for ELLs is a replacement of MEPA testing that was used in 2012-2013 academic year. The Dept. Of Education provides valuable information on ACCESS for ELLS. Similar to the MCAS, DESE posts the results (by school, district, state etc.) on their website.

Scoring

ACCESS comes with different components of the English language including eight categories, four domains and four composite areas (oral language, literacy, comprehension, overall). Raw scores include the number of correct answers but not the difficulty of questions, scaled scores consider the difficulty of questions or the performance of the student over time, and proficiency level scores come with an interpretation of scores, aligning with the six WIDA English language proficiency levels. Please refer to the reference section and Appendix C for more information on WIDA ACCESS ELL.

WIDA ACCESS ELL scores are not utilized in the data analysis since the main scope of this study is focused on specific research questions. However, a sample scatterplot is provided in Appendix J to indicate the relationship between WIDA ACCESS ELL scores and MCAS.

Instrument Resources

Massachusetts Comprehensive Assessment System- MCAS

The following links and slides provide more information on the Next Generation MCAS Assessments,

https://www.doe.mass.edu/mcas/tdd/ https://slideplayer.com/slide/13720954/

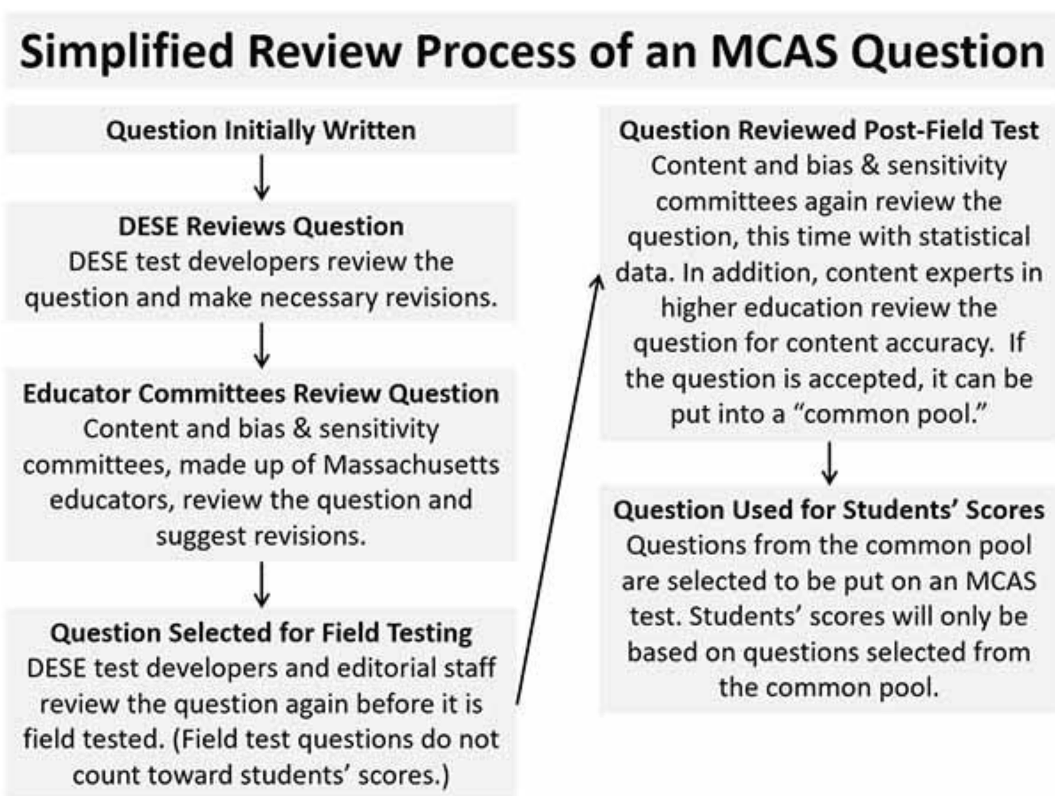
https://www.doe.mass.edu/mcas/tech/?section=techreports

https://www.doe.mass.edu/news/news.aspx?id=21831

https://www.Doe.mass.edu/mcas/cd-reqs/default.html

https://www.cognia.org/wp-content/uploads/2022/01/It-Matters-Student-Engagement-Data-Story.pdf

Review process- https://www.doe.mass.edu/mcas/tdd/



Released 2017 and 2019 MCAS questions,

Massachusetts Comprehensive Assessment System English Language Arts, Grade3 (2017). https://www.doe.mass.edu/mcas/2017/release/gr3-ela.pdf

Massachusetts Comprehensive Assessment System English Language Arts, Grade5 (2019). https://www.doe.mass.edu/mcas/2019/release/gr5-ela.pdf

Massachusetts Comprehensive Assessment System Mathematics, Grade3 (2017). https://www.doe.mass.edu/mcas/2017/release/Gr3-Math.pdf

Massachusetts Comprehensive Assessment System Mathematics, Grade5 (2019). https://www.doe.mass.edu/mcas/2019/release/gr5-math.pdf

Massachusetts Comprehensive Assessment System, Science and Technology/Engineering, Grade 5 (2019). https://www.doe.mass.edu/mcas/2019/release/gr5-ste.pdf

Transition from Legacy MCAS to Next Generation MCAS, https://www.doe.mass.edu/news/news.aspx?id=24639

On MCAS growth, https://www.doe.mass.edu/mcas/growth/GrowthPresentation.pdf

On understanding the Next Generation MCAS: October 2017 https://www.doe.mass.edu/mcas/parents/understand-nextgen.pptx

Massachusetts Common Core Standards, https://www.doe.mass.edu/frameworks/current.html

The Cognitive Abilities Tests- CogAT

Sample questions: refer to pages 9-11 of CogAT product guide to view sample questions, https://www.aacs.org/wp-content/uploads/2012/10/CogAT-Product-Guide-Form-7.pdf

The following links provide more information on the partnership of Riverside's CogAT and Renzulli Learning/ UConn

http://Renzullilearning.com

https://gifted.uconn.edu/about-renzulli-center/

ACCESS WIDA ELL

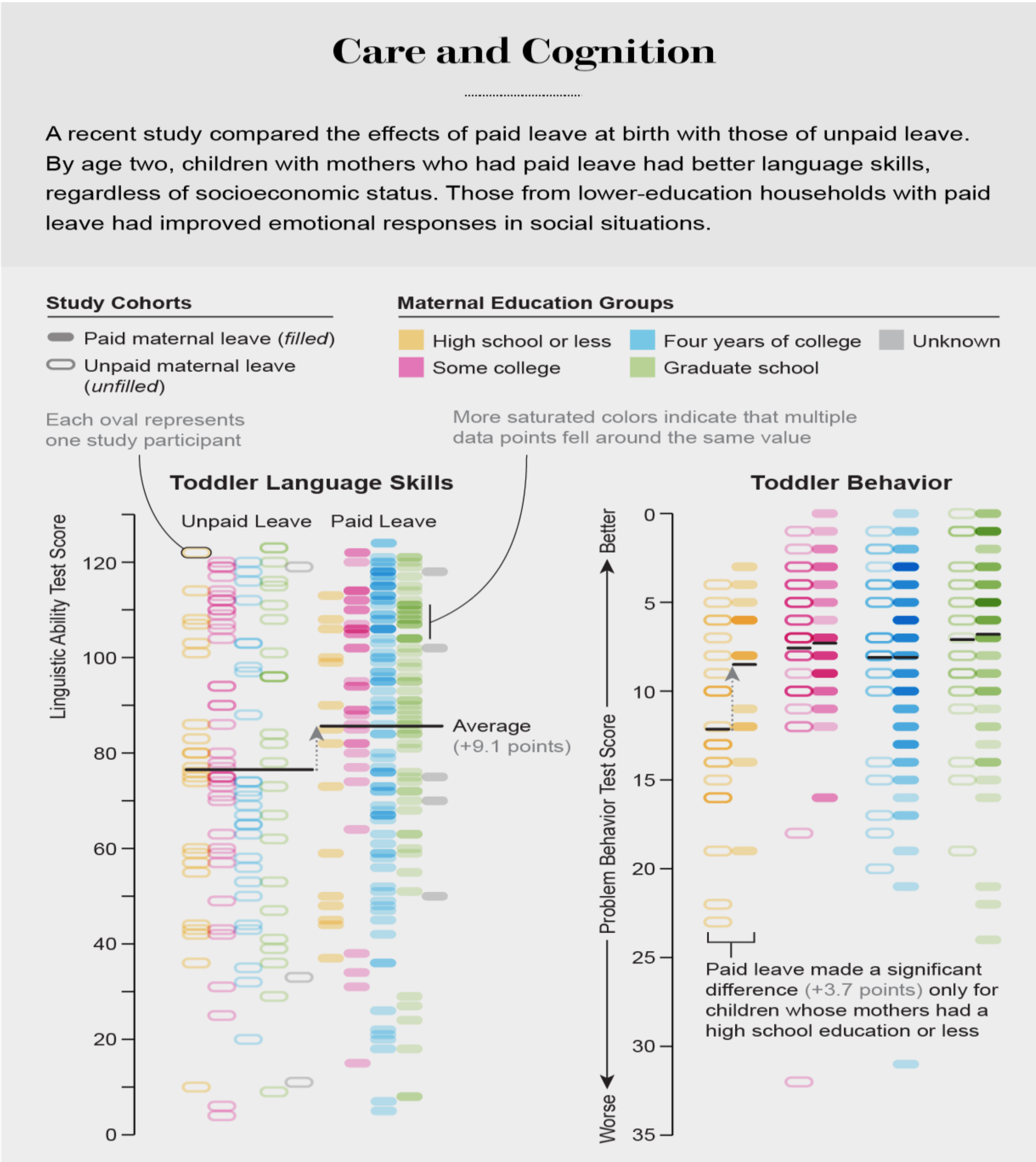
Please refer to the WIDA interpretive guide to view sample questions, https://wida.wisc.edu/sites/default/files/resource/Interpretive-Guide.pdf

The following links provide more information on WIDA ACCESS,

www.Doe.mass.edu/mcas/access/default.html

www.wida.wisc.edu/assess/access

Appendix D



Note. From “The Path to Better Childhoods,” Scientific American, June 2022 by Dana Suskind and Lydia Denworth.

Appendix E

The following websites provide resources on positive psychology

https://ppc.sas.upenn.edu/

http://posneuroscience.org/

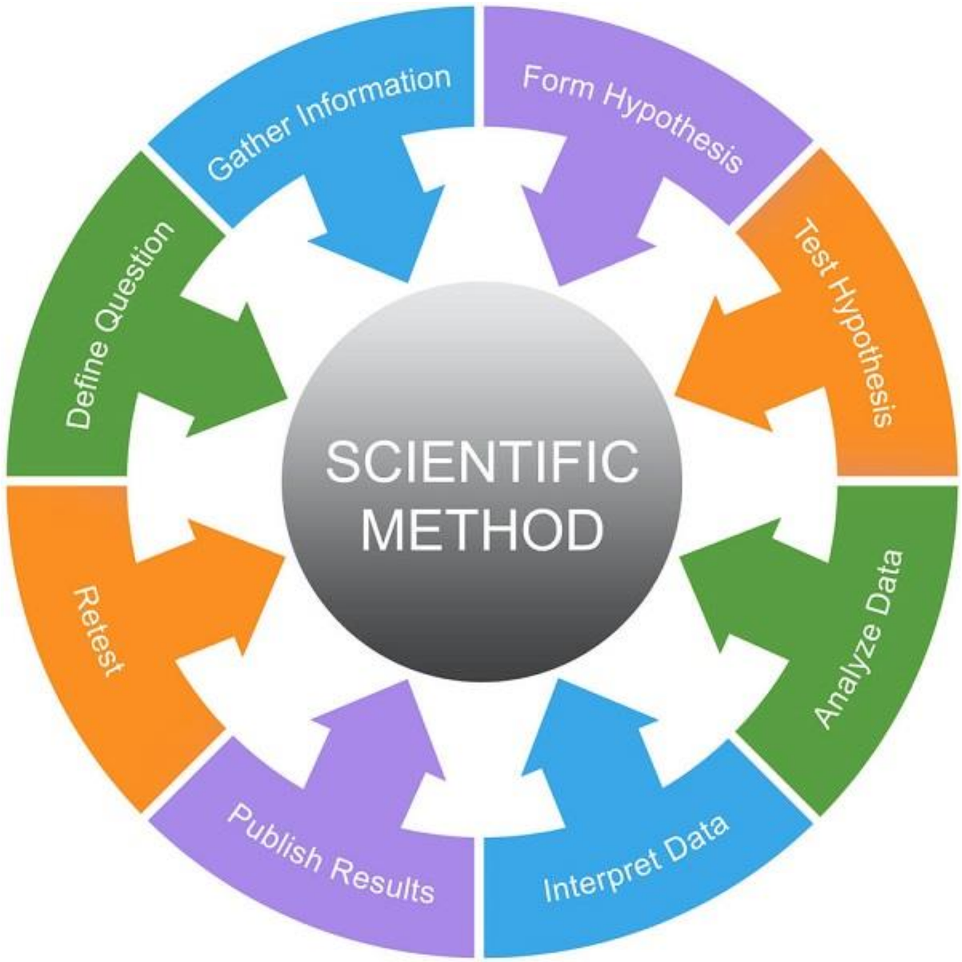
The following websites provide resources on Cognitive Behavioral Therapy for Children

https://www.cdc.gov/childrensmentalhealth/parent-behavior-therapy.html#:~:text=Parents%20can%20be%20involved%20to,of%20their%20thoughts%20and%20feelings.

https://www.healthline.com/health/mental-health/cbt-for-kids

Appendix F

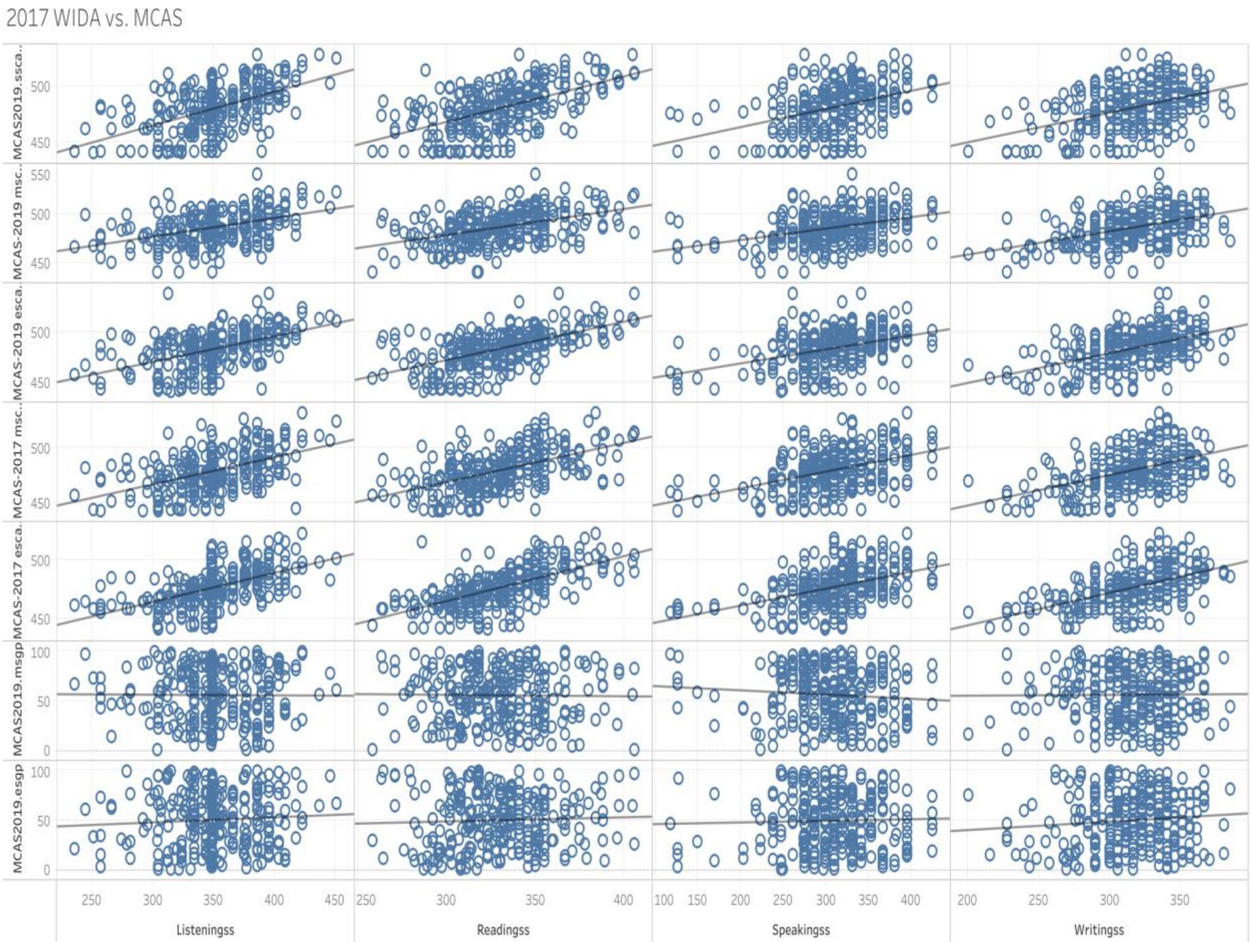
Elements of Scientific Method



Note. From "Scientific Method," Biology Dictionary, November 2020 by BD Editors (https://biologydictionary.net/scientific-method/)

Appendix G

District A's Relationship between WIDA Access and 3rd and 5th Grade MCAS



This scatterplot displays the relationship between WIDA ACCESS ELL scores and MCAS scores. The x-axis indicates the scores of four domains of WIDA ACCESS ELA (listening, reading, speaking, and writing), and the y-axis indicates 3rd and 5th grade MCAS scores (from the bottom MCAS 2019 ELA growth percentile, MCAS 2019 Math growth percentile, MCAS 2017 ELA, MCAS 2019 Math, MCAS 2019 ELA, MCAS 2019 Math, MCAS 2019 STE).

District WIDA ACCESS Quantitative Score Analysis

Dependent	Independent	Coefficient	R-Squared:	P-value:
Gr. 5 MCAS Scaled Math Growth Percentile	Listening	-0.00628	7.71E-05	0.887
Gr. 5 MCAS Scaled ELA Growth Percentile	Listening	0.0508	0.00457	0.269
Gr. 5 MCAS Scaled STE Score	Listening	0.301	0.292	0.0001***
Gr. 5 MCAS Math Score	Listening	0.188	0.184	0.0001***
Gr. 5 MCAS ELA Score	Listening	0.253	0.254	0.0001***
Gr. 3 MCAS ELA Score	Listening	0.249	0.312	0.0001***
Gr. 3 MCAS Math Score	Listening	0.249	0.240	0.0001***
Gr. 5 MCAS Scaled Math Growth Percentile	Reading	-0.0146	0.000246	0.797
Gr. 5 MCAS ELA Growth Percentile	Reading	0.0421	0.00189	0.478
Gr. 5 MCAS STE Score	Reading	0.403	0.314	0.0001***
Gr. 5 MCAS Math Score	Reading	0.264	0.208	0.0001***
Gr. 5 MCAS ELA Score	Reading	0.379	0.341	0.0001***
Gr. 3 MCAS ELA Score	Reading	0.383	0.410	0.0001***
Gr. 3 MCAS Math Score	Reading	0.361	0.297	0.0001***
Gr. 5 MCAS Scaled Math Growth Percentile	Speaking	-0.0423	0.00762	0.165
Gr. 5 MCAS ELA Growth Percentile	Speaking	0.0163	0.000998	0.619
Gr. 5 MCAS STE Score	Speaking	0.161	0.152	0.0001***
Gr. 5 MCAS Math Score	Speaking	0.116	0.134	0.0001***
Gr. 5 MCAS ELA Score	Speaking	0.138	0.149	0.0001***
Gr. 3 MCAS ELA Score	Speaking	0.145	0.210	0.0001***
Gr. 3 MCAS Math Score	Speaking	0.154	0.185	0.0001***
Gr. 5 MCAS Scaled Math Growth Percentile	Writing	0.00839	0.000108	0.866
Gr. 5 MCAS ELA Growth Percentile	Writing	0.0848	0.00976	0.108

Dependent	Independent	Coefficient	R-Squared:	P-value:
Gr. 5 MCAS STE Score	Writing	0.264	0.182	0.0001***
Gr. 5 MCAS Math Score	Writing	0.236	0.207	0.0001***
Gr. 5 MCAS ELA Score	Writing	0.294	0.255	0.0001***
Gr. 3 MCAS ELA Score	Writing	0.278	0.290	0.0001***
Gr. 3 MCAS Math Score	Writing	0.281	0.231	0.0001***

n = 953 (sample complete tests), * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Linear regression results for WIDA and MCAS scores – this table shows the coefficients for the independent variables which indicate the amount of affect they have on the dependent variables. For example, the reading score of ACCESS ELL has a significant impact on both 3rd grade and 5th grade MCAS ELA scores with a coefficient of about 38%, and an R squared of 41% and 34%, respectively.

Appendix H

Question 1 Complete List of Scatterplots

Figure 51

District A 3rd grade CogAT Scores vs. 3rd Grade MCAS ELA

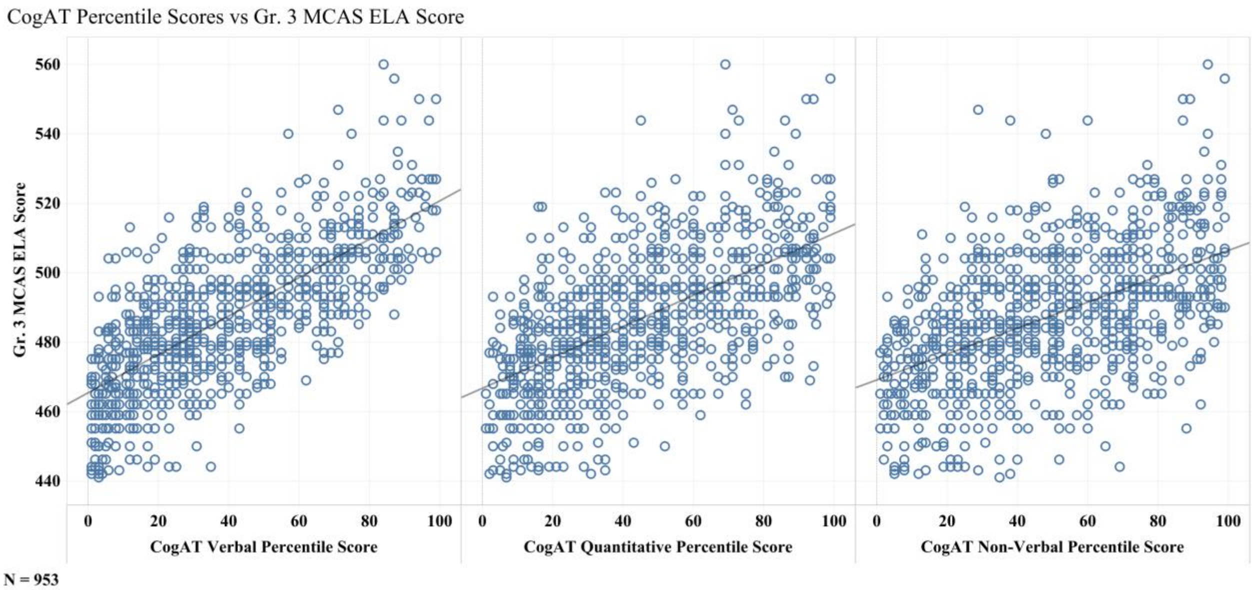


Figure 52

District A 3rd grade CogAT Scores vs. 3rd Grade MCAS Math

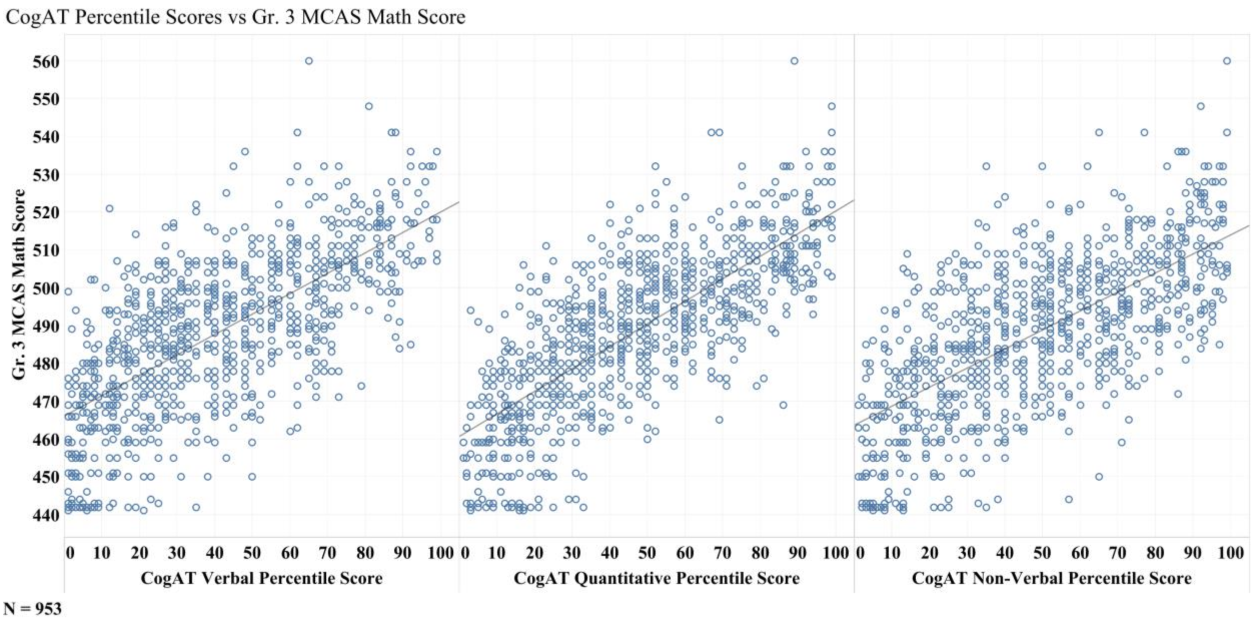


Figure 53

District A 3rd grade CogAT Scores vs. 5th grade MCAS ELA

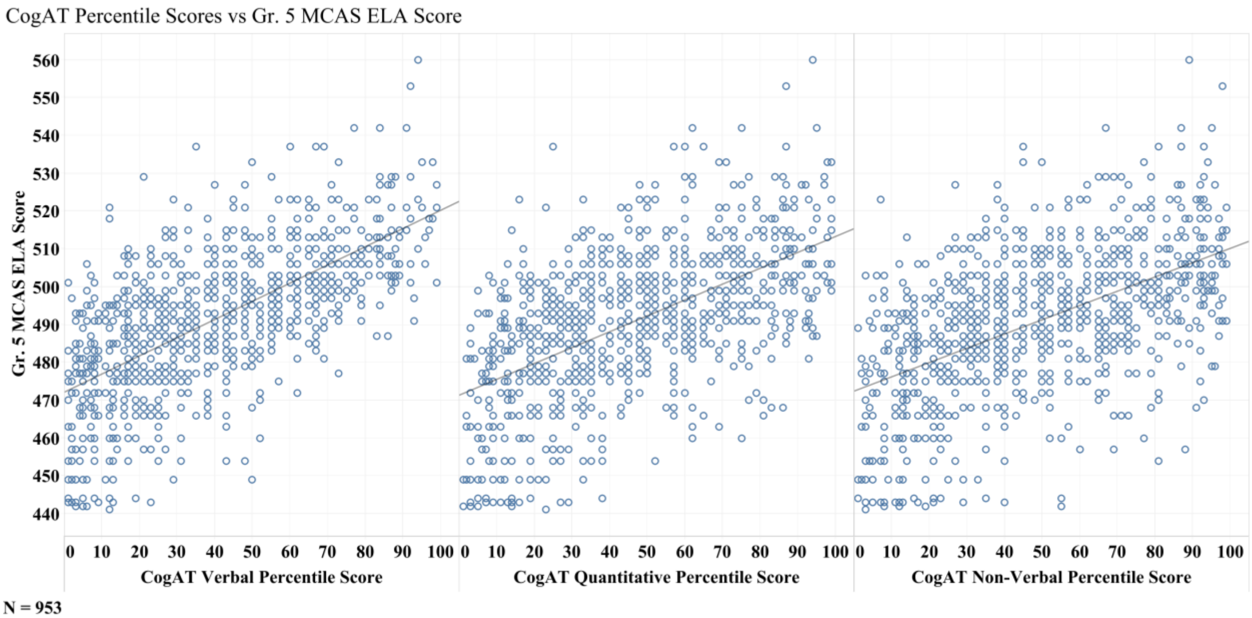


Figure 54

District A 3rd grade CogAT Scores vs. 5th grade MCAS Math

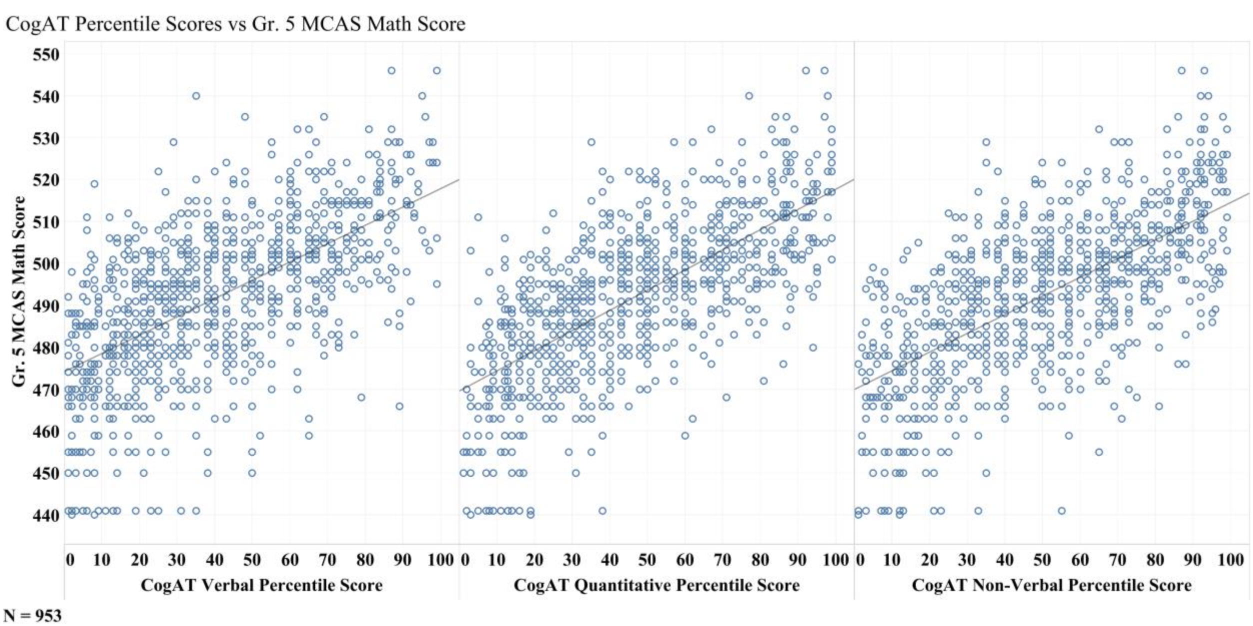


Figure 55

District A 3rd grade CogAT Scores vs. 5th grade MCAS STE

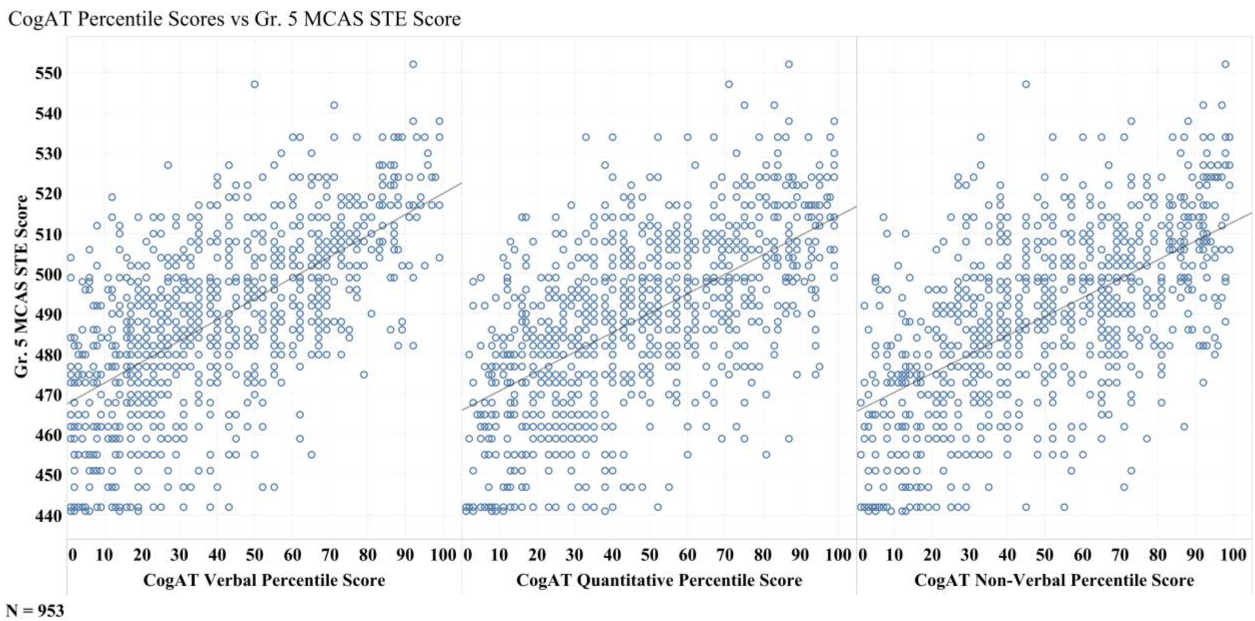


Figure 56

District A 3rd grade MCAS ELA vs. 3rd Grade MCAS Math and 5th Grade MCAS

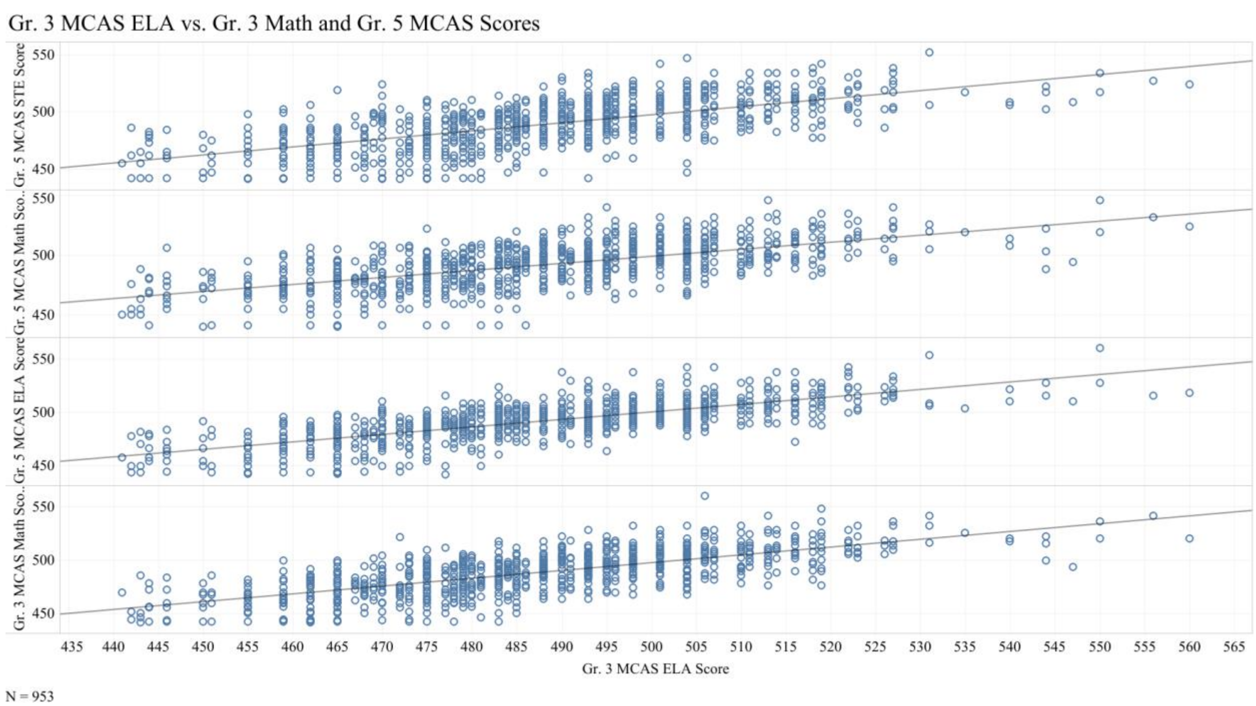
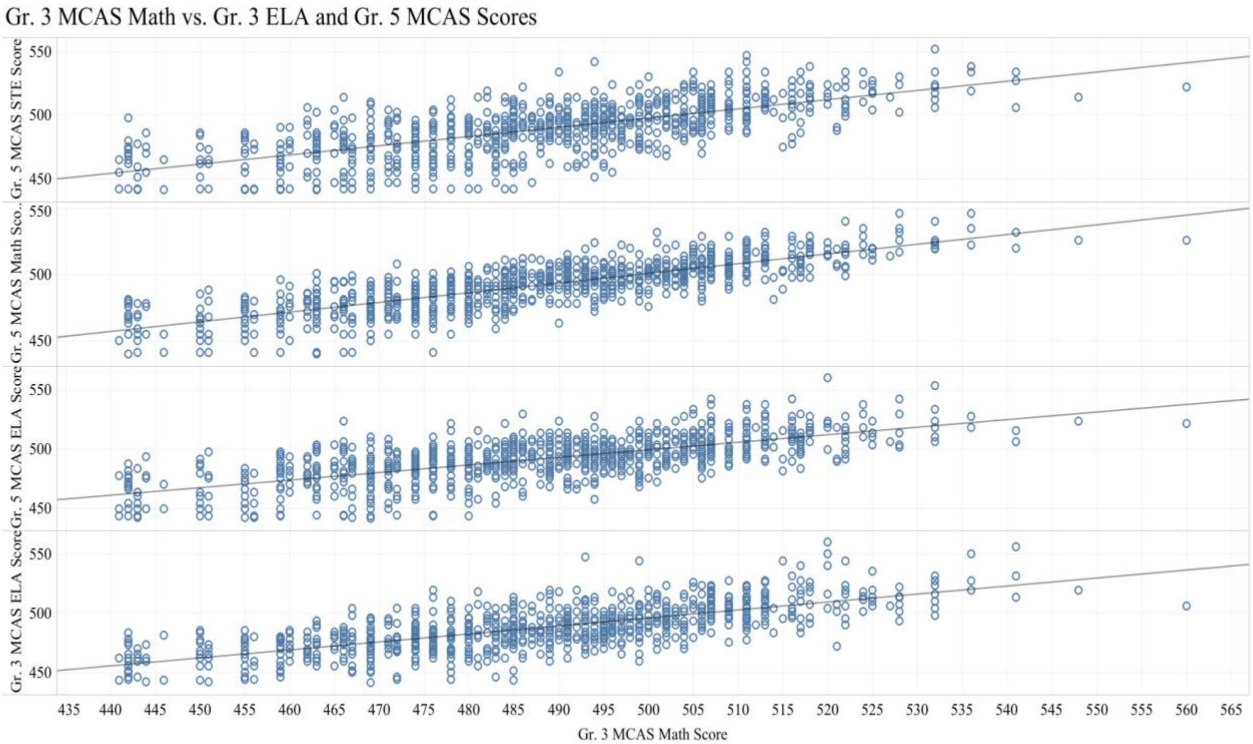


Figure 57

District A 3rd grade MCAS Math vs. 3rd Grade MCAS ELA and 5th Grade MCAS



N = 953

Figure 58

District B 3rd grade CogAT Scores vs. 3rd grade MCAS ELA

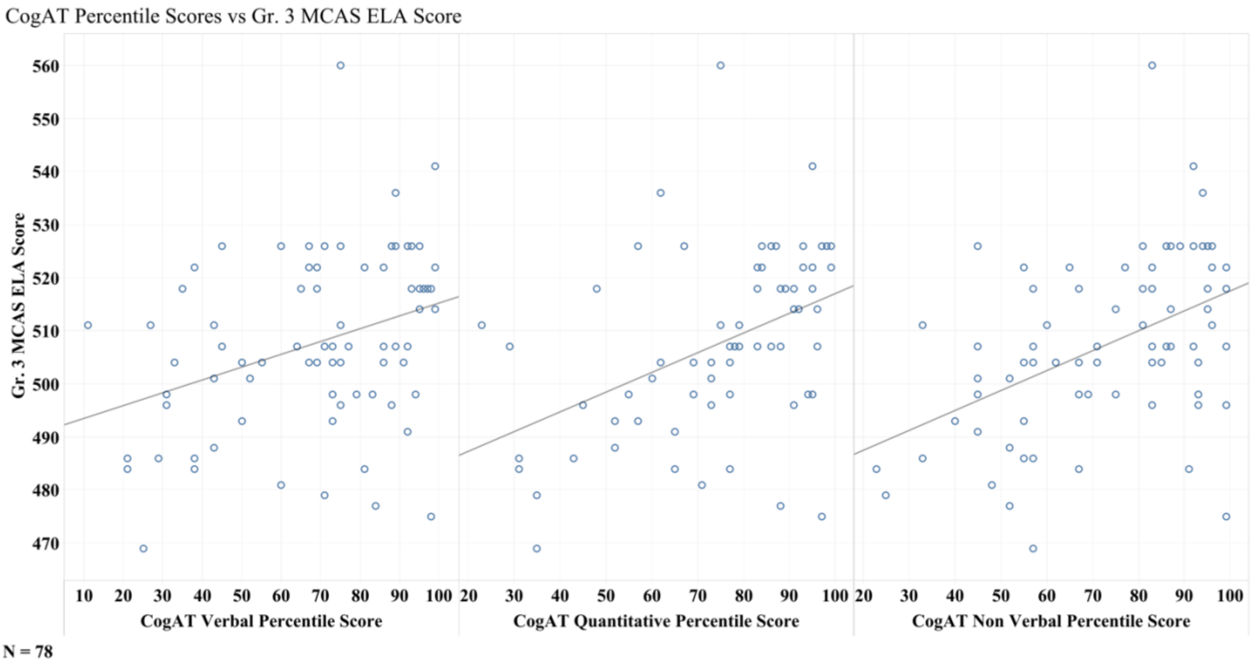


Figure 59

District B 3rd grade CogAT Scores vs. 3rd grade MCAS Math

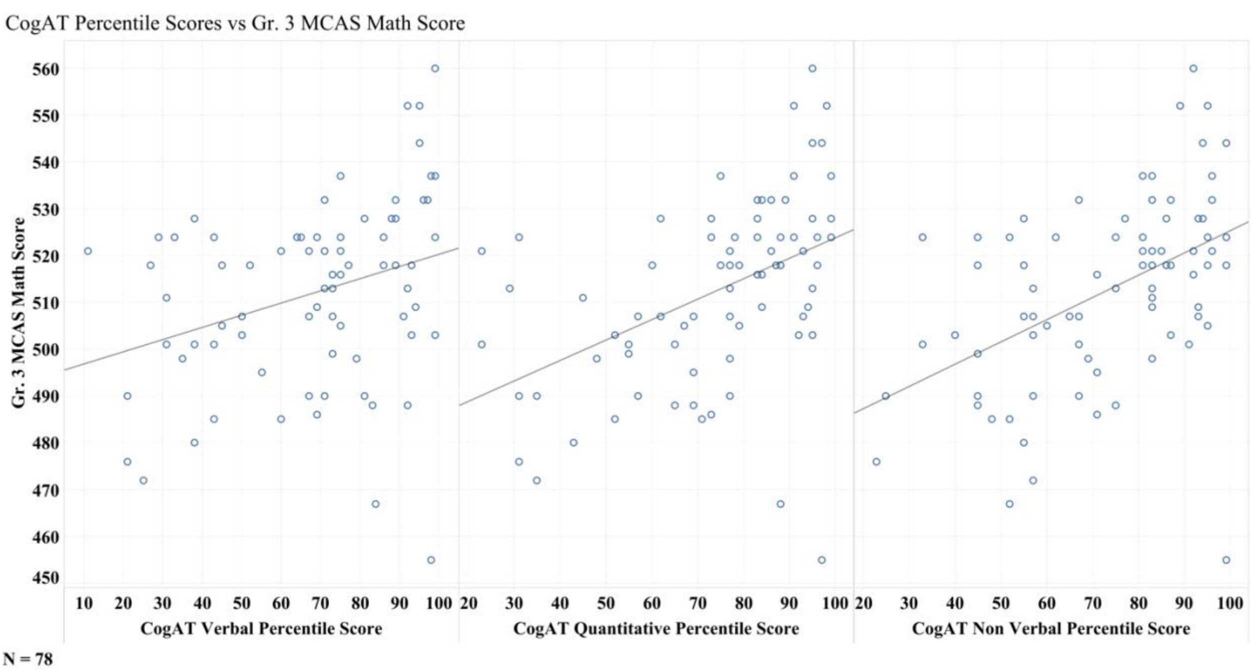


Figure 60

District B 3rd grade CogAT Scores vs. 5th grade MCAS ELA

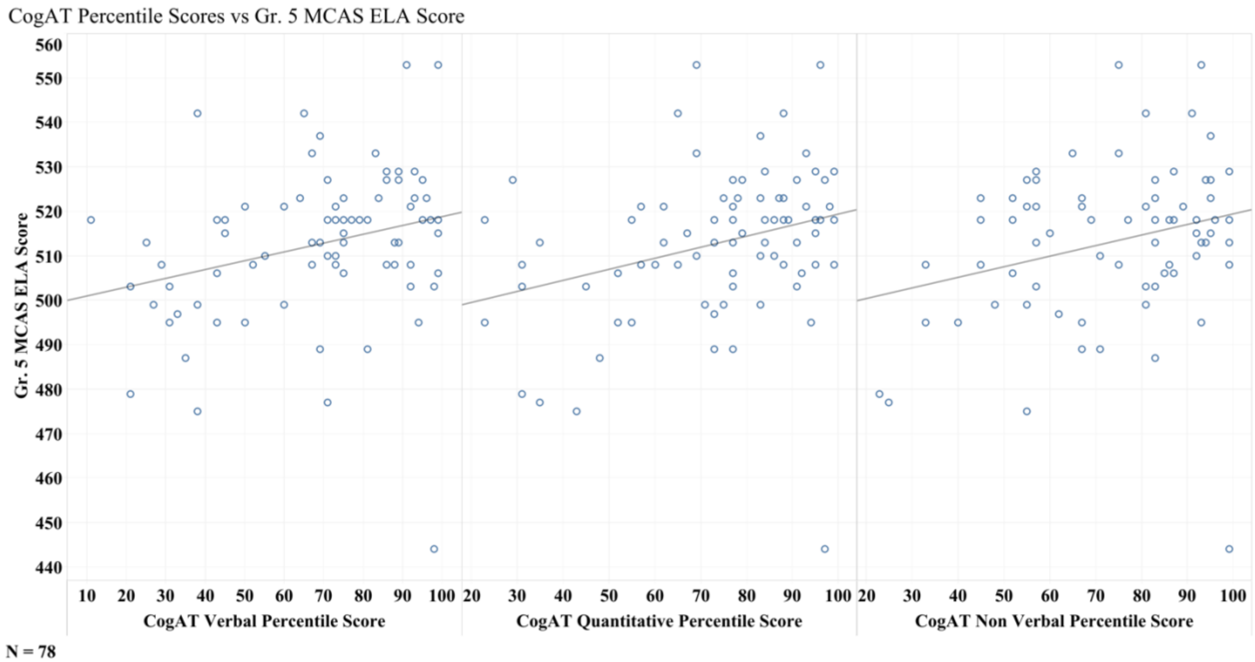


Figure 61

District B 3rd grade CogAT Scores vs. 5th grade MCAS Math

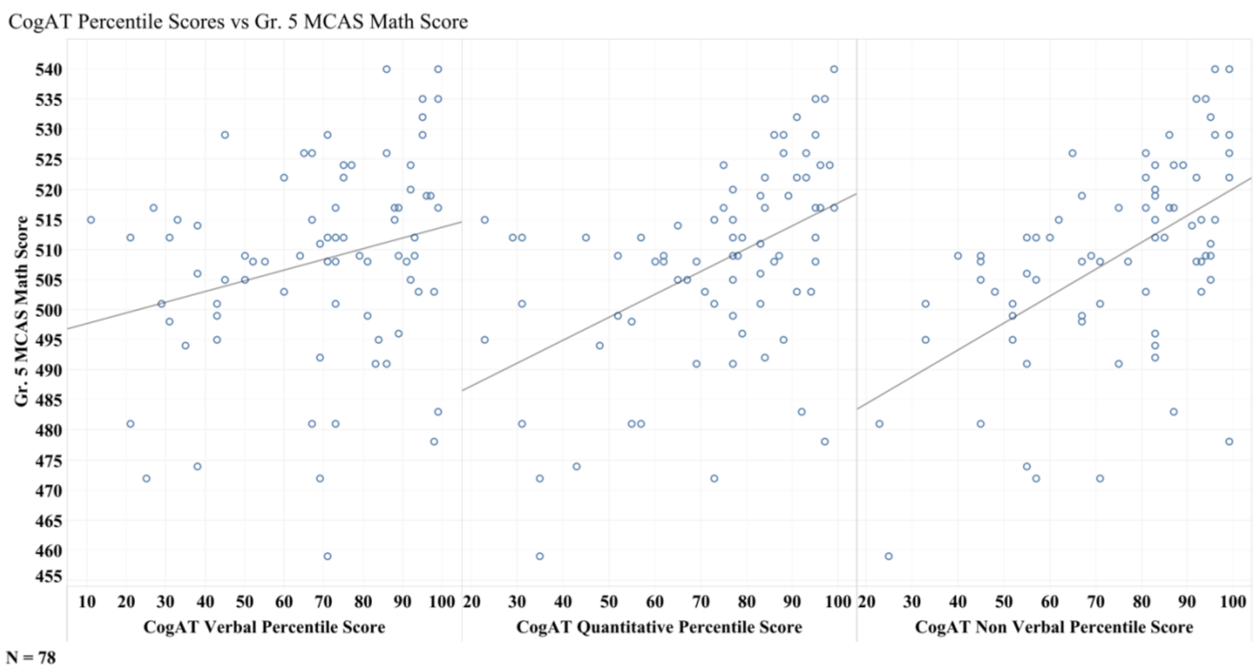


Figure 62

District B 3rd grade CogAT Scores vs. 5th grade MCAS STE

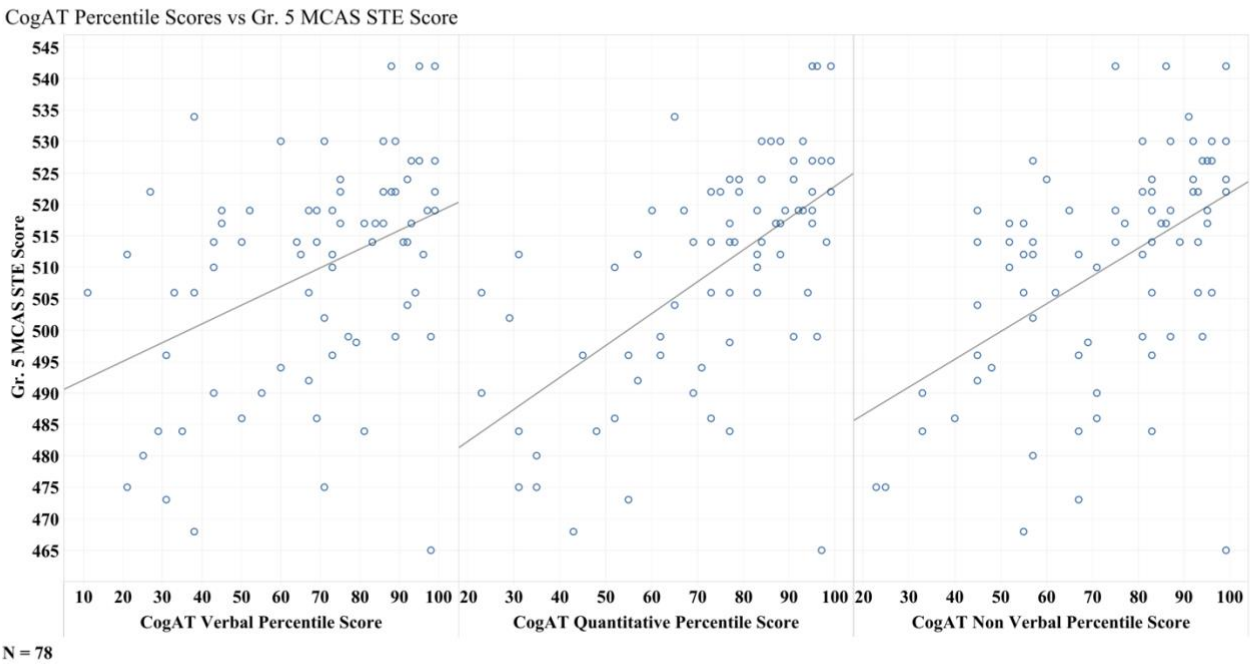


Figure 63

District B 3rd grade MCAS ELA vs. 3rd Grade MCAS Math and 5th Grade MCAS

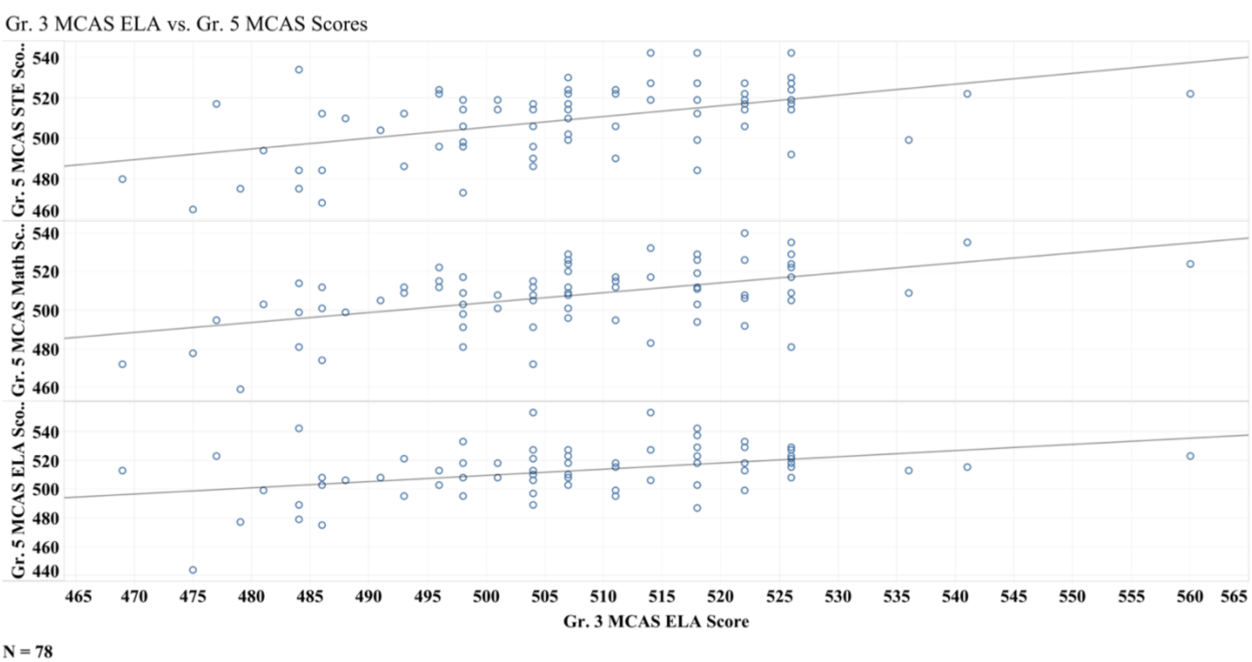
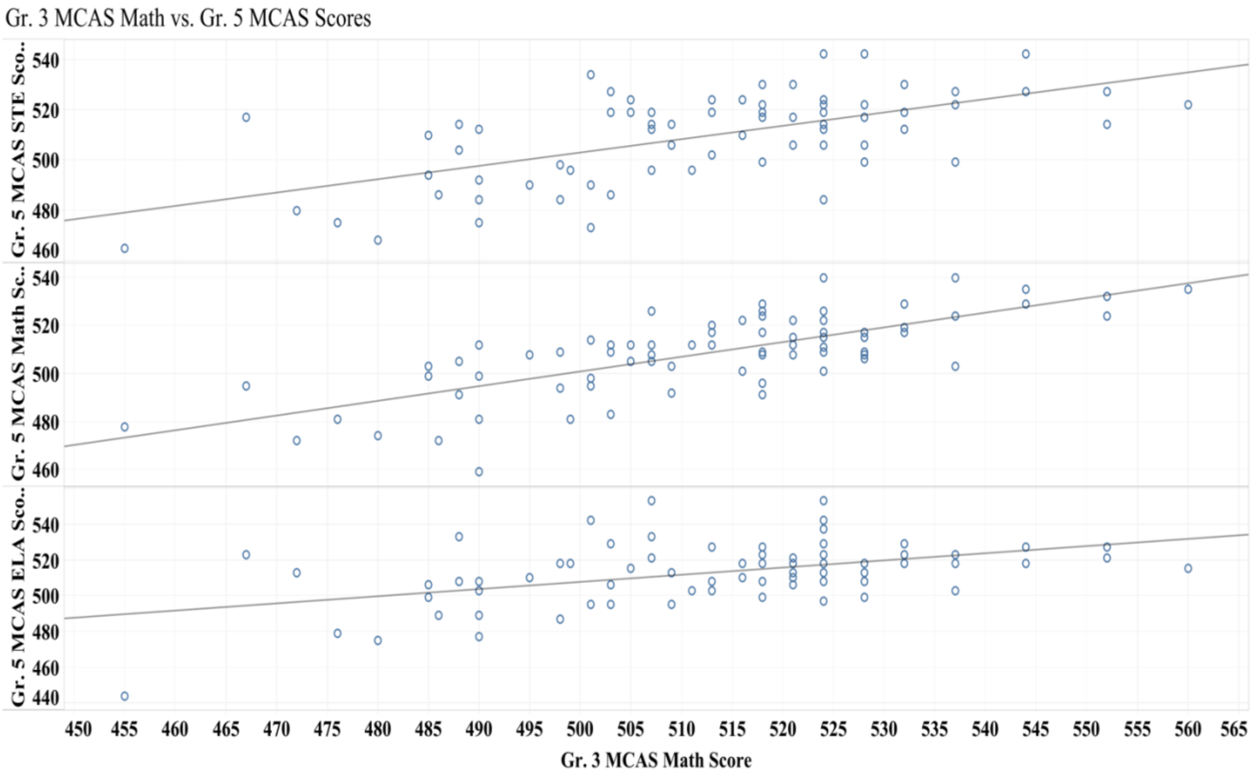


Figure 64

District B 3rd grade MCAS Math vs. 3rd Grade MCAS ELA and 5th Grade MCAS



N = 78

The following scatterplots display the relation between the earlier scores and 5th grade ELA and Math growth percentile. This data complements the other graphs in chapter 3.

Figure 65

District A 3rd grade CogAT Scores vs. 5th grade MCAS ELA SGP

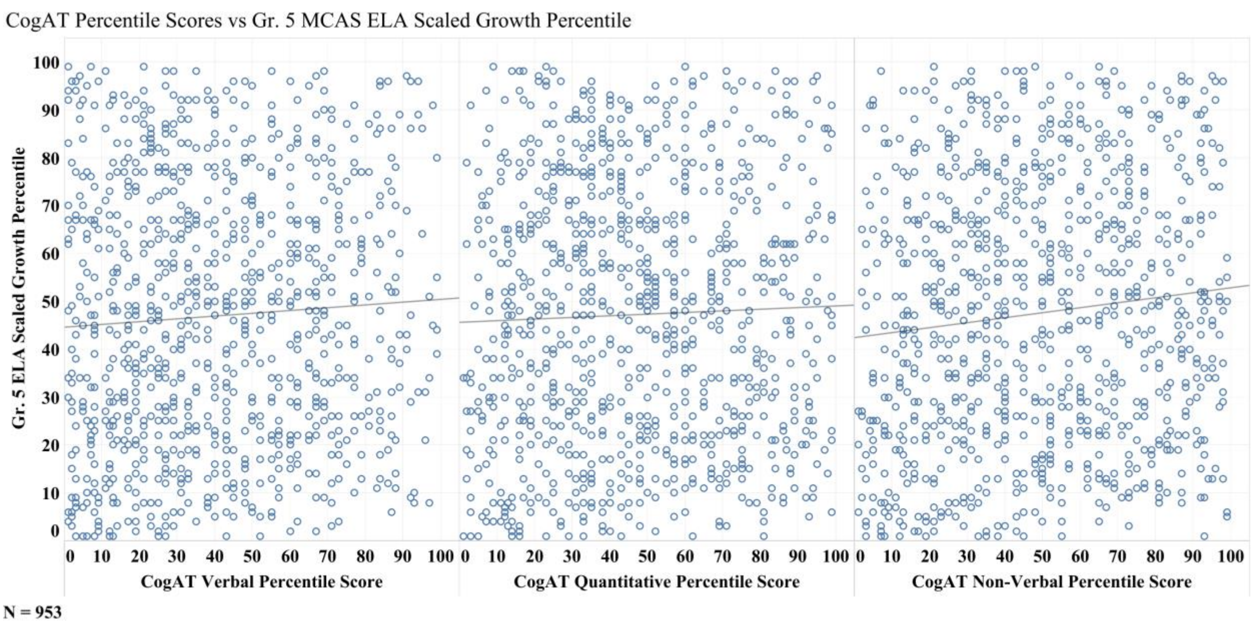


Figure 66

District A 3rd grade CogAT Scores vs. 5th grade MCAS Math SGP

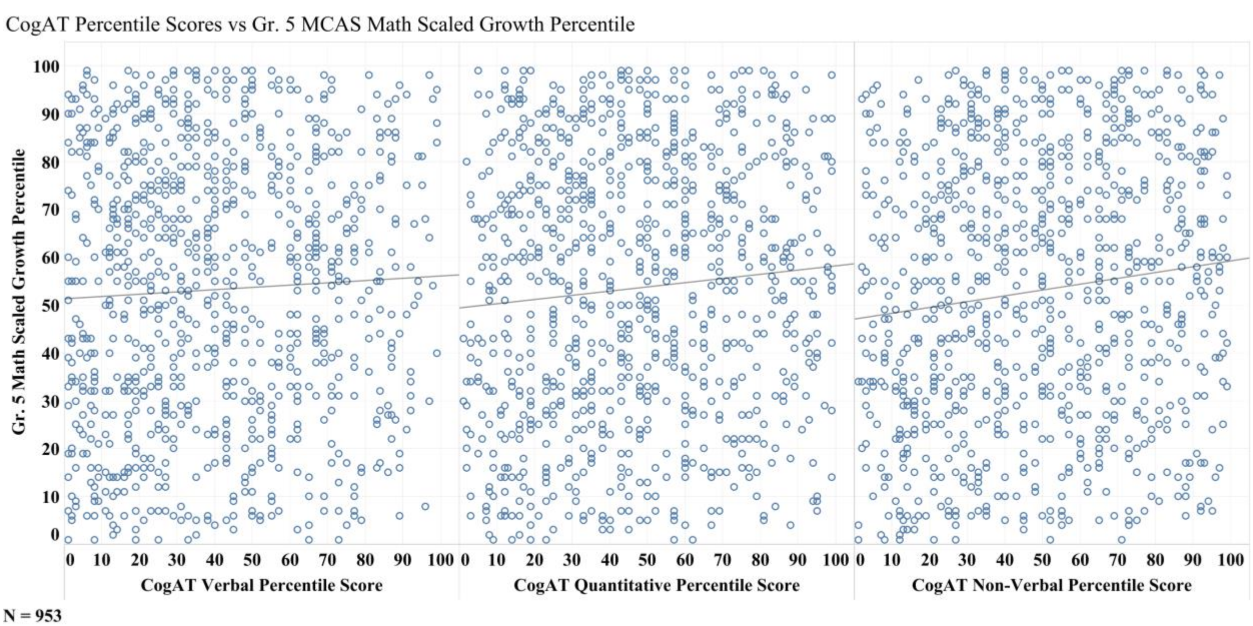
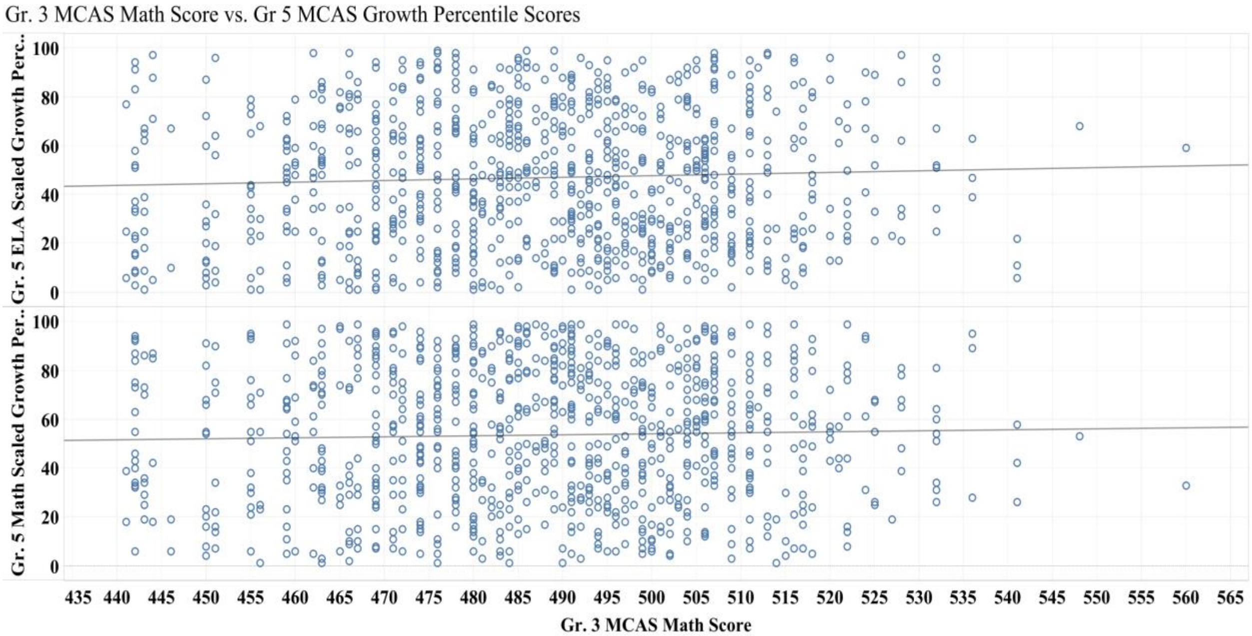


Figure 67

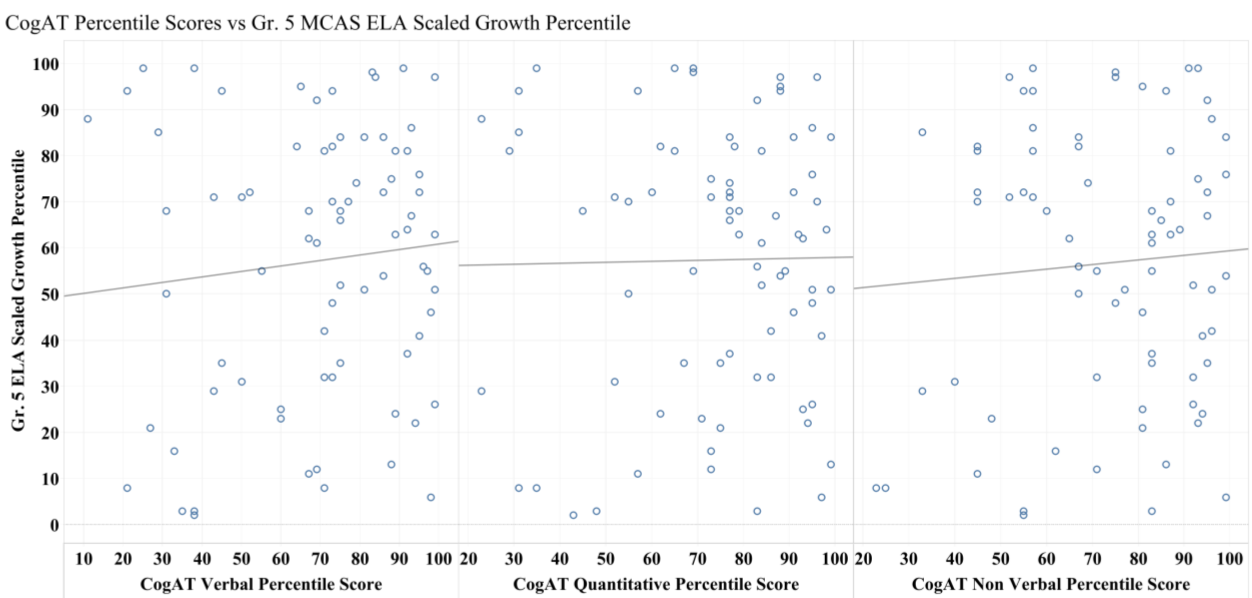
District A 3rd grade MCAS Math Score vs. 5th grade MCAS SGPs



N = 953

Figure 68

District B 3rd grade CogAT Scores vs. 5th grade MCAS ELA SGP



N = 78

Figure 69

District B 3rd grade CogAT Scores vs. 5th grade MCAS Math SGP

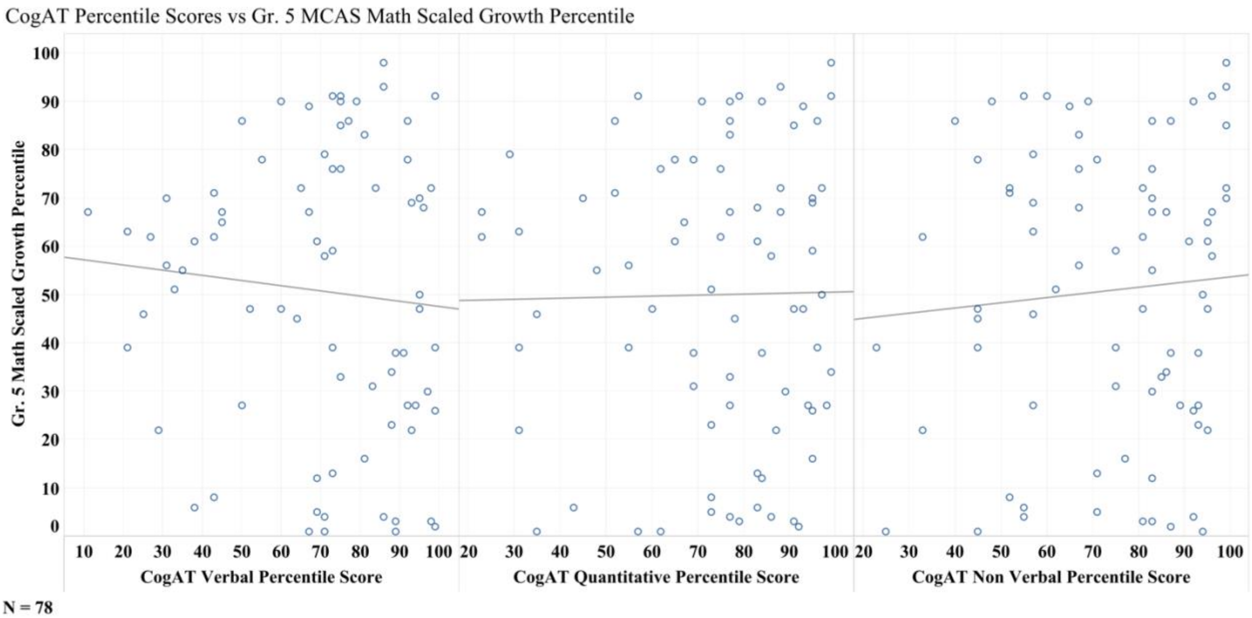


Figure 70

District B 3rd grade MCAS Math Score vs. 5th grade MCAS SGPs