EDUCATIONAL NUEROMYTHS: PREVALENCE AMONG PRE-SERVICE SPECIAL EDUCATION TEACHERS

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Abstract

Educational neuromyths are commonly accepted, erroneous beliefs that contribute to pseudoscientific practice within education (e.g., learning styles, right brain vs. left brain learners, perceptual motor training). The implementation of instructional practices founded upon neuromyths and lacking in empirical evidence diminishes the quality of classroom instruction for k-12 students. Extant research studies indicate strong beliefs in educational neuromyths among teachers in other countries. The purpose of this study was to examine the perspectives of special education pre-service teachers in the United States related to educational neuromyths and corresponding instructional practices. This mixed-methods sequential explanatory study was guided by the following main research questions: (a) What are pre-service teachers' perceptions of educational neuromyths and general knowledge of the brain, learning, and behavior?; (b) What is the relation between perceptions of neuromyths and likelihood to implement corresponding instructional practices?; and (c) What is the relation between demographic factors and beliefs in educational neuromyths and general knowledge of the brain, learning, and behavior? To address these research questions, I administered an adapted survey instrument and conducted online follow-up interviews. Participants' (*n*=131) responses to the survey instrument indicate misperceptions of neuromyths and moderate gaps in general knowledge of the brain, learning, and behavior. Correlation analyses and Kruskal Wallis tests suggest that participants who are aware of neuromyths are slightly more likely to implement effective instructional practices. A moderate, positive correlation was demonstrated between number of education courses and correct *neuromyth* responses. Education courses, not science courses, appear to better prepare students to identify neuromyths. Additionally, data demonstrate moderate positive correlation between perceived level of preparedness and *incorrect* responses to neuromyths statements. Qualitative findings suggest interview participants (*n*=6) are confused by the terminology surrounding educational neuromyths and other instructional approaches (e.g., UDL, differentiation). Recommendations for ameliorating deleterious effects of neuromyths in k-12 classrooms include augmenting current teacher education curricula, increasing pre-service teachers' scientific literacy, and developing collaborative interdisciplinary partnerships with neuroscience researchers.

CHAPTER 1

INTRODUCTION

Looking back over the past 150 years, it is clear the field of special education has made significant inroads in improving educational opportunities for students with exceptionalities (SWE). Presently, the location and the overall quality of services provided for SWE stands in stark contrast to the exclusionary and suspect instructional practices of the past. Additionally, education professionals, along with parents and policy makers, have advocated effectively for the continued advancement of services for SWE both in the classroom and in the community. Although by no means perfect, modern special education in the United States provides much needed services to a diverse segment of our population, and, in general, the quality of the services has improved over time. Many individuals, groups, and social forces have contributed to the development of this field. The history of special education is not monolithic; it is replete with social, cultural, and political complexities.

The story of special education is comprised of many different – and sometimes competing – narratives. Teachers, and the community in general, tend to believe special education services are predicated on ethical and moral grounds, and this belief does hold some merit. This philosophy is evidenced in the tireless work of Elizabeth Farrell, often considered the first special education teacher, in her school on Henry Street in the late 19th century (Gerber, 2011). Moral provenance is also demonstrated by the field's historical connection with the Civil Rights movement and the Women's Rights movement of the 1960s (Shapiro, 1994). Indeed, the early work of many physicians, psychologists, and educators was founded upon moral and ethical obligations to improve the quality of life for SWE (Trent, Artiles, & Englert, 1998). However, the field of special education was not shaped by altruism and morality alone. Moreover, the evolution of the field did not progress in a linear fashion; theoretical and practical advances occurred in fits and starts and were shaped by the cultural, social, political, and economic landscape of its time.

Gerber (2011) suggested that in order to understand the history of special education, it is necessary to consider the large-scale, rapid clashes of the political, philosophical, social, and scientific happenings of the late 19^{th} and 20^{th} century. Gerber characterized the cities in which the United States public education system developed as "teeming laboratories of social, political, and economic experiments" (2011, p. 4). For instance, mass industrialization and immigration both directly contributed to the need for and development of special education. As the U.S population diversified, and the demand for skilled labor increased, public schools functioned as tools for socialization. Compulsory education laws were enacted to prepare America's expanding youth population to become productive members of society. These laws applied to *all* children, thereby inadvertently obliging public schools to confront how and where to educate SWE and other outliers (Hoffman, 1975; Katz, 1968; Yell, Rogers, & Rogers, 1998). Consequently, many early special education programs were partially used as a means to control and segregate SWE, immigrants, and the poor (Lazerson, 1983; Mercer, 1973; Richardson, 1979).

Scientific Inquiry and Special Education

Throughout its history, the field of special education has been influenced by myriad ideological and practical considerations. On one hand, the education of SWE in the United States was incited by a sense of moral responsibility and social justice. On the other hand, Social Darwinism contributed significantly to the instructional approaches used for SWE, and in the creation of separate schools specifically for students considered pathological. It is evident the field of special education has been influenced by both altruistic and pragmatic ideologies, and vestiges of these influences are apparent in modern practice (Kauffman, Ward, & Badar, 2015). Leading scholars of the field opine that issues in special education are perpetual; current topics within the field are echoes of the past, revisited by each generation of educators (Kauffman, 2011). Although special educators do grapple with perennial issues, it is necessary to recognize the remarkable advances that have been made in the field over the past 150 years. It is also vital to acknowledge the decisive role that *scientific inquiry* has played in these advances. Within the field of special education, practitioners' esteem or regard for science has been responsible for considerable progress. Essentially, the recognition of the importance of scientific inquiry within special education research and practice contributed significantly to the professional maturation of the field as demonstrated in the following examples.

Scientific knowledge and empirical inquiry have always played a role in the field of special education. Its history is dotted with examples of forward-thinking researchers who championed the use of empirical evidence to guide their work and improve pedagogical practices for SWE. For instance, in the early 1900s, Elizabeth Farrell collaborated with physicians to assess SWE to determine educational programming (Gerber, 2011). Such practices demonstrate an early appreciation for the importance of multiple data sources in assessment, along with a prescient regard for a biopsychosocial model of disability. Additionally, special education researchers have championed the use of single-case design research for more than fifty years to identify empirically-based instructional practices for SWE (Horner et al, 2005). The historical role of science in special education is also exemplified in the early work of Sam Kirk and Barbara Bateman in their determination to develop a scientific approach for the assessment and instruction of students with learning disabilities (Kirk & Bateman, 1962).

In the past, special education research and practice inconsistently demonstrated a commitment to employing and promoting empirical inquiry and logical analysis. However, modern special education is enjoying a scientific renaissance similar in nature to the manner in which science revolutionized other disciplines in the 20th century (e.g., medicine, agriculture, technology, transportation; Slavin, 2002). Presently, special education researchers and practitioners appear to be more attuned to the importance of empirical evidence and rigorous research methodologies than at any point within the history of the field. Special education professionals are seeking to refine the field via scientific inquiry in two distinct, yet complementary pathways: (a) rigor across multiple research methodologies, and (b) the study of empirical knowledge of internal mechanisms that contribute to human learning and behavior (e.g., neurobiology and genetics).

Changing attitudes toward science and research in special education are reflected in the No Child Left Behind Act (NCLB, 2002) and the Individuals with Disabilities Improvement Act (IDEA, 2004). Both pieces of legislation repeatedly stress the need for schools to implement scientifically based research. The Council for Exceptional Children has worked to increase the rigor of research within the field by developing and disseminating quality indicator guidelines for establishing the evidence base for effective practices (e.g., Odom et al., 2005; Brantlinger, Jimenez, Klingner, Pugach, & Richardson, 2005). There is also growing interest in identifying evidence-based programs and education policies (Munter, Cobb, & Shekell, 2015; Slavin, 2002; Wiseman, 2010). Moreover, appreciation of the importance of replication studies within special education research is growing (Cook, 2014; Travers, Cook, Therrien, & Coyne, 2016). Additionally, researchers have begun to employ strategies from the interdisciplinary field of implementation science to address the persistent research to practice gap prevalent throughout schools nationwide (Cook & Odom, 2013; Dunst, Trivette, & Raab, 2013; Fixsen, Blase, Metz, & Van Dyke, 2013; Hornby, Gable, & Evans, 2013).

The field is also increasingly attending to the burgeoning empirical evidence available about the internal mechanisms that regulate behavior and learning. Most of this knowledge is coming from the increasingly transdisciplinary field of neuroscience. During the latter half of the twentieth century, advances in the fields of electrophysiology, molecular biology, and computational neuroscience have exponentially increased the rate and potential impact of neuroscientific discoveries. These findings are providing researchers with new information about the structure and function of the brain as it relates to learning and behavior, and have the potential to improve instructional practice in the classroom (Goswami, 2004; Black, Meyers, & Hoeft, 2015). Currently, a neurologically grounded approach to educational research and pedagogy is contributing to the growing emphasis on research-based, scientific findings within special educational theory and practice.

Neuroscience and Special Education

Neuroscience and special education appear to be particularly felicitous fields for collaborative endeavors. Recent research from neuroscience can provide special educators with information about atypical neural development with a clarity that was not available in the past. These insights are of particular importance to special educators in their efforts to identify and treat academic and behavioral exceptionalities. Advances in neuroscience can provide special educators with biological insights into the etiologies of academic and behavioral deviations. It is indeed an exciting era for special education, as researchers and practitioners can use this data to improve the identification, treatment, and assessment of SWE.

The rationale for the specific inclusion of neurological considerations within the field of education is by no means a new phenomenon. It was almost a century ago that Edward Thorndike (1926), commonly considered the father of educational psychology, claimed there was a link between intellect and the physiological components of neurons and their accessory organs. The idea of forging an intentional partnership between education and neuroscience emerged in the 1960s. At that time, neuropsychologist and neuroeducation harbinger, William Gaddes (1968) asserted that neuropsychological approaches should be applied to the study of learning disabilities. After a dearth of activity in this area for twenty years, researchers Jocelyn Fuller and James Glendening (1985) once again called for the application of neuroscientific findings within the field of education.

During the early 2000s, the systematic study of neuroscience and education began to take root. This new field of study has been called many things, including: (a) neuroeducation; (b) Mind, Brain, and Education Science; (c) educational neuroscience; (d) cognitive education; and (e) Learning and the Brain (Schwartz, 2015). Each one of these initiatives refers to separate, but complementary, efforts of various academic and public organizations. Although the objectives vary among these established programs, their underlying philosophies are similar. All of the movements are dedicated to the application of neuroscientific principles to educational theory and practice. Currently, neuroscience has the potential to augment special education research and practice in three areas: (a) early identification, (b) instructional practices, and (c) research design.

Early Identification

It is generally accepted that the early identification of a disability has the potential to improve behavior or academic outcomes related to that disability. Early intervention has the capacity to prevent and/or ameliorate a number of developmental risk factors for children, and has been shown to positively affect school outcomes for students with disabilities (Guralnick, 1993). Early intervention has a long and rich history within the field of special education and has been given significant support from the federal government (Conroy, 2011). It is the most universally recognized means to address and remediate disabilities within the school system, and, as Tankersley and Kamp asserted, “early intervention is prevention” (1996, p. 42).

Although early intervention is deemed to be of paramount significance in the prevention and remediation of disabilities, all too frequently students are not identified with a disability at an early age. Many students are well into elementary or middle school before a disability is identified, precluding implementation of appropriate supports and services during pre-school and elementary years. Recent advances in neuroscience have the ability to improve the accuracy and timeliness of the identification of a disability, and increase access to effective interventions at a young age (Butterworth, Varma, & Laurillard, 2011). Neuroimaging procedures, particularly electroencephalograms (EEGs), functional magnetic resonance imaging (fMRIs), and Magnetoencephalography (MEG) can assist in the early identification of highly heritable conditions. For example, attention deficit hyperactivity disorder (ADHD) and dyslexia are common exceptionalities studied within the field of special education and are highly heritable conditions. Through neuroimaging, researchers have been able to identify key physiological markers of dyslexia (Eckert, 2003; Meyler et al., 2008; Lizarazu, 2015; Molfese, 2000; Vanvooren, 2015; Waldie et al., 2013) and ADHD (de Celis et al, 2014; Dickstein, Bannon, Castellanos, & Milham, 2006; Dutra, Baltar, & Monte-Silva, 2016; Gilbert, Isaacs, Augusta, Macneil, & Mostofsky, 2011). Generally, these two conditions do not become readily apparent until children are of school age, thereby precluding the benefits of early intervention. Neuroimaging can augment typical screening practices (e.g., behavioral screening tools, achievement tests, Response to Intervention) and potentially lead to the provision of appropriate early intervention services.

Instructional Practices

Identifying and implementing effective instructional practices is critical for the improving the learning outcomes of SWE. Instructional practices are identified as effective on the basis of evidence from educational research studies that traditionally use behavioral measures to determine effectiveness (e.g., observations, achievement scores, checklists). Although this research has merit, neuroscience has the capacity to confirm and reinforce the use of extant practices by providing additional empirical data to support the evidence base of such practices. Advances in neuroimaging offer novel understandings of the anatomy of the brain as it relates to cognition and behavior. Additionally, a more refined understanding of neural plasticity and synaptogenesis helps to explain the value of several extant instructional practices. Examples of these practices include: (a) modeling, (b) visualization and visual supports, (c) motivation, and (d) engagement. Specific research in this area will be detailed in Chapter 2.

Research Applications

Neuroimaging techniques also have the potential to assist researchers in assessing the effectiveness of academic and behavioral interventions in contemporary research studies. Through the use of EEGs, researchers are now able to triangulate behavioral data with neurobiological data to assess specific variables and outcomes within a research study; researchers are now able to use pre and post intervention images to help establish significance. For example, Temple et al. (2003) and Hillman et al. (2014) integrated neuroimaging in their data collection for research studies on dyslexia and attention. The purpose of the images was to demonstrate whether the interventions contributed to relevant modification of neural organization. Neuroimaging can provide researchers with specific neurological snapshots related to the implemented interventions. Extant research of this type indicates neuroimaging can provide a more holistic picture of the effects of specific interventions on SWE, and has the potential to increase the development and implementation of effective interventions.

Statement of the Problem

Encouraged by these exciting new research possibilities, it is no surprise that a variety of stakeholders have become enamored by the potential for neuroeducation to improve educational practice, particularly for SWE. A systematic, multimodal approach to educational research and practice – a methodology validated by both neurobiological markers and behavioral observations – appears as a promising next step in the field of special education. It is evident that incorporation of neurobiological factors within the study of individual differences has the potential to significantly improve the rigor of special education research and improve interventions and outcomes for SWEs. However, it is critical that all stakeholders currently interested in the potential of neuroeducation proceed with cautious optimism. Excitement about the possibilities of this emerging discipline must be tempered by logic and critical consumption of emerging research findings, and educators should be wary of individuals or programs that oversimplify or provide inappropriate interpretations of complex neuroscience research. If critical consumption of neuroeducation claims does not occur, teachers and scholars alike may fall prey to the dangers of pseudoscience; and practices and policies from neuroscience research may actually do more harm than good for students in the classroom. Misinterpretation of scientific findings, and the inappropriate applications of these findings, will invariably promulgate erroneous beliefs about the neurological processes of learning. Unfortunately, this is an ongoing phenomenon, and this type of misinformation is commonly referred to as “neuromyths.”

The original use of the term “neuromyth” can most likely be attributed to neurosurgeon Alan Crockard. In the 1980s, he became frustrated by how readily unscientific ideas about the brain were being embraced by the medical community (Crockard, 1996). The Brain and Learning Project of the Organization for Economic Co-operation and Development (OECD) later appropriated the term for use within the education field, warning that neuromyths were beginning to influence education policy and practice (OECD, 2002). More recently, Pasquinelli summarized neuromyths as "misconceptions about mind and brain functioning" (p. 1, 2013).

It is important to note that neuromyths are not typically born out of intentional or malevolent manipulation of data by self-serving scholars or corporations. There are, in fact, several benign processes that sustain the development and circulation of these myths. In her study of neuromyths, Pasquinelli (2013) identified a minimum of four conditions that generate neuromyths: (a) the distortion of scientific facts (e.g., gross simplification of scientific data), (b) the creation of beliefs that are offspring of erroneous scientific findings, (c) the misinterpretation of experimental results, and (d) the rapid growth of neurophilia (the public's appetite for and unguarded consumption of brain news in the popular press).

When one considers the many ways in which neuromyths are perpetuated, it is not surprising to witness their infiltration of educational research and practice. In fact, most educational researchers can easily call to mind several neuromyths that have circulated within the field for many years – even after scientific evidence has provided data demonstrating the fallacious premise upon which these practices were founded. For example, "learning styles," is a concept widely endorsed and accepted within educational sectors and in other industries (Scott, 2010). However, reviews of studies on this popular concept do not demonstrate sufficient evidence to support the claim that student outcomes improve when teachers attempt to match instruction to the learning styles of individual students (Coffield et al., 2004; Curry, 1990; Scott, 2010). Many other common neuromyths within education have been deemed as questionable practices based on scientific scrutiny, but still enjoy wide-spread circulation throughout schools, such as multiple intelligences theory (Gardner, 1983), perceptual motor programs (e.g., Brain Gym®; Dennison & Dennsion, 1986), and right- vs. left-brain instruction (Jensen, 2008).

Neuromyths in educational research and practice are problematic for many reasons. First and foremost, the implementation of instructional practices founded upon neuromyths can reduce the use of truly effective instructional approaches within the classroom. In order to consistently improve student academic and behavioral outcomes, especially for students with exceptionalities, teachers must rely upon scientifically validated instruction. In other words, teachers need to use what has been proved to work. Additionally, when school districts incorporate curricula based upon neuromyths, a significant amount of time, money, and effort is misallocated. Moreover, when administrators and teachers select to implement practices informed by neuromyths, they are preventing the evolution of the field of neuroeducation – an enterprise that holds documented promise for increasing the outcomes of all students in the classroom.

Seven peer-reviewed research studies have explored the prevalence of neuromyths among pre-service and in-service teachers (Dekker, Lee, Howard-Jones, & Jolles, 2012; Deligiannidi & Howard-Jones, 2015; Gleichgerrcht, Luttges, Salvarezza, & Campos, 2015; Karakus, Howard-Jones, & Jay, 2015; Pei, Howard-Jones, Zhang, Liu, & Jin, 2015; Rato, Abreu, & Castro-Caldas, 2013; Tardif, Doudin, & Meylan, 2015). Each study focused on participants in specific geographic regions, including the United

Kingdom and Netherlands, Latin America, Greece, Portugal, Turkey, Eastern China, and Switzerland. Across all studies, results indicate that pre-service and in-service teachers believe many neuromyths and are prone to various misconceptions about the brain related to learning and behavior. Extant research demonstrates that neuromyths are pervasive amongst educators in many areas around the globe.

Presently, research has not examined the prevalence or predictors of neuromyths among pre-service and in-service teachers in the United States. In order to address specious instructional practices in the United States, it is necessary to explore which, if any, neuromyths are currently circulating among educators. Additionally, in order to address the influence of neuromyths in the United States, it is important to identify how beliefs in neuromyths may influence instructional decisions. Research studies have shown that in-service and pre-service teachers are interested in learning more about neuroscience and "brain-based" curricula (Pickering & Howard-Jones, 2007; Serpati & Looughan, 2012). Unfortunately, pre-service and in-service teachers are generally not provided with the training to identify neuromyths and instructional practices based upon pseudoscience. In order to systematically support teacher educators in addressing this problem, it is necessary to first gather baseline data about the prevalence and implications of specific neuromyths in the United States; this data can inform future decisions on how to best address pseudoscientific beliefs within education research and practice.

Purpose of Study and Research Questions

The purpose of this research study is to investigate the ubiquity of neuromyths among pre-service teachers in the United States, and to explore how neuromyths may influence decision-making. My research questions are:

1. What are pre-service teachers' perceptions of educational neuromyths and general knowledge of the brain, learning, and behavior?
2. What is the self-reported likelihood of pre-service teachers to implement an array of instructional practices (effective and ineffective)?
3. Is there a relationship between perceptions of neuromyths and likelihood to implement corresponding instructional practices?
4. Is there a relationship between demographic factors and beliefs in educational neuromyths and general knowledge of the brain, learning, and behavior?
5. What are participants' perceived levels of preparedness in educationally relevant neuroscience literacy, what is their interest in learning about this topic, and what sources do they use for information about this topic?

CHAPTER 2

LITERATURE REVIEW

Presently, neuroscience research is generating a growing body of knowledge that is of particular relevance for special education research and practice. For instance, a significant amount of research emerging from developmental neuroscience examines the neurobiological differences between typical and atypical neural development (e.g., Happé, & Frith, 2014; Silk, Redcay, & Fox, 2014; Samyn, Wiersema, Bijttebier, & Roeyers, 2014). The field of special education seeks to understand and service students who experience atypical development and are considered outliers among the general population. Accordingly, developmental neuroscience has the potential to provide valuable insights into the etiology of exceptionalities. Additionally, research from the branches of behavioral neuroscience and cognitive neuroscience explores an array of cognitive and behavioral conditions that have historically necessitated special education services and supports. In general, current neuroscience research activity holds promise for producing knowledge of considerable import for teaching students with exceptionalities. However, there is reluctance within the field of special education to wholeheartedly embrace the translation of neuroscientific findings to special education practice.

Within the field of disability studies, there remains marked resistance to biological or genetic explanations of individual conditions. Proponents of the "social model" of disability contend that disability is an exclusively social construct and is developed and maintained through acts of social oppression (Abberley, 1987; Oliver, 1996). Many supporters of the social model of disability oppose the use of labels and assert disabilities can be eradicated by changing the socio-political climate of communities (Reindal, 1995). The use of neuroscientific data for special education research appears anathema to the fundamental tenets of the social model of disability. However, this does not need to be the case. It is not beneficial for individuals with exceptionalities to be conceptualized within a binary, dichotomous paradigm that polarizes the social model and the medical model.

Fortunately, leaders within the field of special education have begun to articulate convincing arguments for recognizing both the social and the biological dimensions of exceptionality. In their timely article on the need to embrace a biological understanding of disability, Anastasiou and Kauffman (2013) argued:

> What is needed is a unified and multidimensional understanding of disabilities, clarifying the relationship among the biological and cultural, individual and social, psychological and behavioral, intrinsic and external factors affecting the lives of people without eliminating one of these levels of analysis (p. 454).

Their sentiments are similarly supported by special educator Paul Cooper (2014). In his recent writing on social, emotional, and behavioral disorders, Cooper argued for the value of a bio-psycho-social model of disability. He claimed that an understanding of the multiple factors (i.e., biological, social, and psychological) that comprise exceptionality could improve interventions and outcomes for individuals with exceptionalities.

Currently, the field of special education is at a critical nexus. The opportunities to enhance the field's understandings of exceptionality and to improve the quality of educational interventions have never seemed so promising. This is evidenced by a growing movement within the field to prioritize rigorous research methods and implement evidence based instructional strategies. The incorporation of neuroscientific research into special education research and practice – neuroeducation – appears both promising and complementary given the current tenor of special education research, and holds promise for improving outcomes for SWE.

There are many challenges inherent to the development of an interdisciplinary collaboration between neuroscience and education. Unfortunately, these challenges can forestall the utilization of relevant neuroscience research to special education research and practice. As articulated in Chapter One, a significant challenge within neuroeducation is the misapplication or poor translation of neuroscientific research to educational practice. This has been an ongoing challenge within the field of neuroeducation, and can be seen in the prevalence and rapid proliferation of neuromyths. These misperceptions about the brain are problematic because they prevent clear communication between professionals across disciplines. Additionally, neuromyths can distract well-meaning educators and steer them away from research-based instructional approaches and strategies. The existence of neuromyths threatens the field of neuroeducation and may preclude the beneficial application of neuroscience research to early identification, instructional practices, and research design within the field of special education.

To facilitate a productive relationship between neuroscience and education, it is necessary for researchers to explore the origins and impact of neuromyths. Accordingly, in this chapter, I will provide: (a) a brief history of neuroscience and education, (b) selected promising applications of neuroscientific research to educational research and practice, (c) a discussion of the translational complexities within neuroeducation and the role of neuromyths, and (d) a review of extant research on neuromyths.

Overview of Neuroscience and Education

Brief History

When reviewing the long history of neuroscience and education, the lack of references to the field of special education is quite noticeable. However, these omissions do not mean that neuroscience holds little import for a field that explicitly studies and targets academic and behavioral deviations. As mentioned previously, the field of neuroscience has long been concerned with studying atypical development of the human brain in terms of behavior and cognition.

There are many examples of early intellectuals attempting to make sense of the brain and establish direct links between the brain and behavior. These advances were made long before the establishment of the particular field of neuroscience. For instance, in the 10^{th} century, the Persian physicist, Alhazen, made important contributions to the understanding of how sensorimotor perceptions are interpreted in the brain and subsequently translated into thought (Steffans, 2006). During the Renaissance, Leonardo da Vinci and Andreas Vesalius began to draw anatomical sketches of the human brain in efforts to establish common references for shared research. In the 1800s, researchers such as Paul Broca (1862), Carl Wernicke (1874), and Santiago Ramon y Cajal (1911) made strides in locating and isolating brain domains and regions aligned to specific behaviors. Although localization of brain function is now questioned as an overly-simplification, these scholars correctly identified regions of the brain that are principally involved in specific cognitive activity.

In 1949, Donald Hebb published the seminal text, *The Organization of Behavior*, in which he established the Hebbian synapse principal. Simply stated, this rule suggests that “neurons that fire together, wire together” (Tokuhama-Espinosa, 2011, p. 46). Subsequently, Jean Piaget (1928), a developmental psychologist, established a theoretical foundation that squarely tied biology to education. Other early progenitors of neuroscience and education include Hans Seyle (1956), who researched the impact of stress on cognition, and Roger Sperry (1968), who studied the role of hemispheric dominance on achievement. Although some of the claims of these early founders were later disproven, their research helped to forge the foundation of the interface between neuroscience and education.

As mentioned in Chapter One, the neuropsychologist William Gaddes (1968) explicitly asserted that neuropsychological findings should be applied to the study of learning disabilities. This marks a significant leap forward in the research of neurobiological processes for the purposes of addressing cognitive abnormalities. After a dearth of activity in this area for twenty years, researchers Jocelyn Fuller and James Glendening (1985) once again called for the application of neuroscientific findings within the field of education. In their article, they coined the term “neuroeducator.” I include their description verbatim here, as their words presciently describe a profession that, thirty years later, is still in the making.

> The role of the neuroeducator is to study and understand the known relationships of brain/behavior and apply those relationships to the learning process. This individual will integrate the contributions of many disciplines in order to prescribe precision educational programs for the child with learning

> difficulties, as well as the gifted child. In the school system the neuroeducator will be a consultant to special programs. Trained in educational and neuropsychological testing and interpretation, he or she will be able to assess specific neuropsychological and learning problems leading toward the development of a prescription of in depth programs of learning. (p. 137)

Their mandate was evocative, but not effective. It still took quite some time before institutions, scholarly organizations, or for-profit industries began to seriously explore the benefits of a collaborative effort between neuroscience and education.

Quite possibly the two most catalyzing events in terms of shaping neuroeducation occurred in the 1980s and 1990s. The field of neuroscience came into being during the mid-1980s, around the same time the American Educational Research Association formed the "Brain, Neurosciences, and Education Special Interest Group." This is the oldest special interest group dedicated to the linkage of neuroscience and education in the United States. Additionally, per the recommendation of leading neuroscience researchers, the United States Congress and George Walker Bush coined the 1990s as the "Decade of the Brain." This resolution stimulated a variety of initiatives that benefited neuroscience research. Along with the National Institutes of Health and the National Institute of Mental Health, researchers released numerous publications and developed many research programs addressing the role of neuroscience in behavior and disease. The "Decade of the Brain" resolution contributed to the growing public awareness of brain structure and function and the exciting potential applications of such discoveries (Jones & Mendell, 1999).

In 1993, the influential "Mind, Brain, and Behavior" initiative was established by an interfaculty initiative at Harvard University; this project developed into the "Mind, Brain, and Education Institute" in 2004. This organization produced the first peer-reviewed academic journal dedicated to research related to neuroscience and education, and established the professional organization, the International Mind, Brain, and Education Society. In 2007, this organization hosted its first conference and was attended by participants representing 14 countries. Simultaneously, other organizations dedicated to this same purpose were being established internationally. Of significance is the graduate program in neuroscience and education at the University of Bristol. Paul Howard-Jones is one of the key researchers involved in this program, and has written extensively about neuroeducation. His *Introducing Neuroeducational Research: Neuroscience, Education, and the Brain from Contexts to Practice* (Howard-Jones, 2010) is a seminal text in the field of neuroeducation. In addition to these two programs, several other institutions, academic programs, and commercial endeavors related to neuroscience and education have been established over the past decade. (See Appendix A for a list of neuroeducation institutes, societies, programs, publications, and conferences.)

Of concern, however, is that to date, only one program has been established specifically for the study of neuroscience and special education. This program is a doctoral program in applied neuroscience and special education at George Washington University. Considering the relevance of neuroeducation to the education of SWE, an exploration of the development of curricula or academic programs that focus on special education and neuroscience is warranted.

Selected Applications

Although there is growing enthusiasm about the application of neuroscientific findings to the field of education, much of the excitement, especially in the popular press, is speculative and pseudoscientific. However, the number of peer-reviewed publications about neuroscience and education is growing steadily, and many of the findings provide additional validation for commonly used educational interventions, and confirm foundational tenets of special education instruction. Special educators can use neuroscientific insights to strengthen their confidence in existing educational interventions and practices of the field. Additionally, emerging neuroscience research is relevant for early identification, teacher perceptions, and special education research design. In the following section, I will provide a description of relevant applications in the following areas: (a) early identification, (b) common instructional practices, (c) responsiveness to intervention, and (d) teacher perceptions.

Early Identification. In order to ameliorate deleterious effects of a condition (e.g., dyslexia, ADHD), it is helpful to understand the condition in its entirety. When educators are aware of the specific cause(s) of a disability, they are able to develop targeted prevention and remediation plans due to specific etiological knowledge. Increased awareness of the potential causes of disabilities can assist special educators in significantly improving the prevention and treatment of disabilities. However, within the school system, the unstated standard diagnostic tool is to "wait to see" which students fail (Reynolds, Shaywitz, 2009). Because of this model, numerous students struggle in school for an unnecessary length of time. During this time – while teachers wait for students to fail – they fall behind academically (particularly in reading) and suffer psychologically from the frustration and humiliation they experience on a daily basis in school.

Dyslexia. Dyslexia has the longest and most robust neurophysiological research base among high-incidence disabilities. With the improvement of neuroimaging techniques, particularly EEGs and fMRIs, researchers have amassed a significant amount of data revealing the neurophysiological idiosyncrasies of dyslexia. Several meta-analyses of neuroimaging studies have been conducted. These publications aggregate common structural abnormalities of individuals with dyslexia (Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008; Richlan, Kronbichler, & Wimmer, 2009; Richlan, Kronbichler, & Wimmer, 2013). In general, individuals with dyslexia demonstrate hypoactivation of the left temporo-parietal cortex when processing letters, words, and sentences (Eckert, 2003; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008). In addition, many individuals with dyslexia exhibit hyperactivation of the right posterior parietal cortex (Waldie, 2013). Researchers are currently investigating whether this hyperactivation is an organic structural indicator of dyslexia, or if the hyperactivation of the right posterior parietal cortex develops over time to compensate for the hypoactivation of the left temporo-parietal cortex. Other recent research has found that individuals with dyslexia demonstrate hypoactivation in the left pre-frontal cortex when presented with rapid acoustic stimuli (Vanvooren, 2015). Additionally, EEGs have shown hypoactivation in the left pre-frontal and inferior cortices (Cangoz et al., 2013). Through neuroimaging techniques, researchers have been able to identify these specific neural indicators. This knowledge can be used to improve early identification systems of assessment as demonstrated by research studies in neurodevelopmental biology.

Longitudinal research studies that follow at-risk individuals, preferably from infancy, before a disability is apparent, are considered the gold standard of research within the field of neurodevelopmental biology (Goswami, 2015). These studies have the potential to augment current early identification practices. For instance, Molfese (2000) conducted a longitudinal study on dyslexia. In this study, the researchers used EEGs to track the electrical brain activity of 186 infants in response to speech and non-speech syllables. Event related potentials (electrophysiological neural responses) were recorded in response to phonological and non-phonological sounds in the left and right frontal, temporal, and parietal regions of the brain. Subsequently, the research team administered IQ tests and reading achievement tests to the study participants at 8 years of age. When the EEG findings of the infants were compared to their assessment scores at 8 years of age, researchers found they were able to hypothesize the infants' future reading ability with remarkable precision. Based upon the EEG findings at infancy, the research team was able to predict with 81.25% accuracy whether the eight-year olds were typical readers, poor readers, or children diagnosed with dyslexia.

This type of research demonstrates the promise neuroscience holds for improving the provision of early intervention services for SWE. Dyslexia is a highly heritable condition. Therefore, at-risk infants (infants from families with a history of dyslexia) could be screened via non-invasive imaging techniques to determine the likelihood of a dyslexia diagnosis. This assessment would allow for the provision of timely proactive interventions, whether than waiting for children to experience failure in reading and other areas before implementing valuable interventions.

ADHD. ADHD is a common neuro-pathological condition among children, which is usually not apparent until children begin formal schooling. Traditionally, behavioral screening tools have been used to evaluate children for ADHD (Wolraich, Feurer, Hannah, & Baumgaertel, 2003). However, EEGs and genomic analysis can now provide neurobiological indicators of a child's risk for ADHD. Similar to dyslexia, ADHD is a highly heritable condition, and imaging techniques can assist in the early identification and treatment of ADHD.

In general, neuroimaging studies have demonstrated that children with ADHD experience hypoactivation of the pre-frontal cortex, and atypical activation in related areas including the thalamus, the basal ganglia, and specific regions of the parietal cortex (Dickstein, Bannon, Castellanos, & Milham, 2006). Several meta-analyses of these neuroimaging studies have been conducted. These publications aggregate common structural abnormalities of individuals with ADHD (Cortese et al., 2012; Dickstein, Bannon, Xavier Castellanos, & Milham, 2006; Nakao, Radua, Rubia, & Mataix-Cols, 2011). In addition, considerable evidence indicates the pathomechanism of the dopaminergic system in individuals with ADHD (del Campo et al., 2013; Kirley et al., 2002; Spencer et al., 2013).

In addition to knowledge gleaned about the neuroanatomy of ADHD through imaging studies, genetic analysis has also identified stereotypic markers of this condition. Based upon genomic analysis, researchers have identified several risk alleles that appear to contribute to the development of ADHD. In particular, the protein of the DAT gene and the methionine allele of the COMT gene indicate a propensity towards ADHD behaviors (Tai et al, 2016; Spencer et al., 2007; Sun,Yuan, Shen, Xiong, & Wu, 2014).

Research findings demonstrate that the presence of these risk genes inhibits the degradation of dopamine and norepinephrine, neurotransmitters responsible for motivation and attention. This neurobiological data can improve the timeliness and accuracy of early assessment systems by augmenting traditional ADHD behavioral screening tools. Currently, psychiatrists have the ability to detect ADHD risk alleles by swabbing the inside of a child's cheek and sending the sample to a lab for genetic analysis. At-risk individuals would benefit from this minimally invasive technology because it could potentially lead to the provision of early intervention services needed to improve long-term behavioral and academic outcomes.

Instructional practices. Many specific instructional practices commonly considered to be effective by teacher preparation programs are supported by research that uses behavioral measures (e.g., observations, achievement scores, checklists). Although this research has merit, and should be sufficient to warrant implementation of the practices within the classroom, neuroscience has the capacity to reinforce the use of extant practices by elucidating the mechanisms by which they affect change in student behavior and academic performance. I will outline the implications for this as it relates to four different instructional areas: (a) modeling, (b) visualization and visual supports, c) motivation, and (d) engagement.

Modeling. A strong research base indicates that direct instruction yields significant gains for students with learning disabilities and emotional and behavioral disorders (Carnine, & Fletcher- Janzen, 2013; Gersten, 1985; Nelson, Johnson, & Marchand-Martella, 1996). Modeling is an integral component of the direct instruction procedure. Although special educators have a long history of supporting the use of modeling in classroom instruction, this approach is not without contention. There are still many educators who support a more constructivist approach, and believe that children learn best through experimentation and discovery (Henson, 2015; Larochelle, Bednarz, & Garrison, 1998). Neuroscience can provide additional support for the effectiveness of modeling in the classroom, and its ability to support all learners. Ideally, this can assist in broadening the support for the use of modeling in the instruction of all students.

The discovery of mirror neurons has significant implication for the understanding of how individuals learn through observation (Cook, Bird, Catmur, Press, & Heyes, 2014; Iacoboni, 2009). A mirror neuron is a neuron that is electrically activated when an individual either performs a specific behavior, or merely observes the performance of that behavior. Imaging research demonstrates that when an individual observes the actions of another individual the inferior frontal cortex and superior parietal lobes are activated (Cook et al., 2014; Keysers & Gazzola, 2010; Rizzolatti & Craighero, 2004). These are the same regions activated by the person performing the task. During modeling, metaphorically, the observer becomes the actor. Literally, during modeling, the observer develops a neurologically imprinted understanding of the task being modeled. This discovery strengthens the understanding of the importance of modeling, especially for SWE. As students observe a teacher perform a specific skill, they are, in a sense, creating a neurological imprint of the behaviors necessary to complete the same skill. This enables the observer to be more successful when they perform the task, and provides further validation for the use of modeling in instructional practice.

Visualization and visual supports. It has been known for quite some time that visualization is an effective strategy for supporting the learning process of individuals with learning and behavioral challenges (Hallahan, Kauffman, & Pullen, 2011). Special educators are trained to provide students with visual supports to augment the auditory information presented during instruction and incorporate concrete visual representations and manipulatives to help students visualize abstract ideas. In addition, teachers regularly call upon students to make mental pictures in their heads, or "mind" movies, as they are reading. This routine instructional approach is supported by educational research across a number of content areas and exceptionalities. For instance, a considerable amount of research supports the use of visual supports and visualization to improve the outcomes of learners with disabilities related to mathematics (Eilam, 2011; Phillips, Norris, & Macnab, 2010; Presmeg, 2006), science (Gilbert, 2005; Wu, Krajcik, & Soloway, 2001), reading (Phillips, Norris, & Macnab, 2010; Sharp et al., 1995), and communication (Ayres & Hopf, 1985). In addition, the use of visual cues for students with autism enjoys a wide research base (Dettmer, Simpson, Myles, & Ganz, 2000; Johnston, Nelson, Evans, & Palazolo, 2003; Lorimer, Simpson, Myles, & Ganz, 2002; Savner, & Myles, 2000). This is not an exhaustive list of the many areas in which visual cues and visualization can support students with exceptionalities in the classroom, but it represents the broad range of its appeal.

Historically, the use of visual supports and visualization has been justified by the use of behavioral assessments to determine their effectiveness. However, current neuroscience research offers special educators another perspective to validate and support this practice. Extant neuroscience research provides a functional explanation of this instructional approach, and creates an opportunity for teachers to understand the connection between observable behaviors and brain function. In general, visual cues and visualization are able to elicit meaningful and pedagogically efficacious responses in students. This phenomenon is directly supported by neuroscientific research in this area. Through neuroimaging, it is now known that visualization produces strong physiological responses in learners, and that visualizing an object recruits most of the brain regions activated by seeing it (Kosslyn, 2005). The active engagement of many brain regions related to a specific event strengthens comprehension, retention, and generalization. These findings provide support for the use of visuals and visualization in the classroom.

Motivation. Motivation has been a salient area of research within the field of special education for several decades (Pintrich, 2003; Weiner, 1990). The ability to motivate SWE in the classroom is a requisite skill for all special education teachers. Quite simply, if teachers are not able to motivate their students to participate or engage, students will not acquire academic or behavioral skills at an appropriate rate. This issue is of particular relevance for special education teachers because many students with learning and behavioral disabilities do not regularly demonstrate intrinsic motivation or function in a general state of “learned helplessness.” A large body of special education research has explored the concept of learned helplessness in relation to SWE. Many of these students experience an overwhelming sense of powerlessness, a low frustration threshold, and diminished capacity to persist (Alderman, 2013; Hen & Goroshit, 2014; Valås, 2001).

Special education teachers regularly service students who experience learned helplessness. In order to motivate these struggling students, they frequently use tangible and intangible reinforcers. Within the area of behavior modification and applied behavior analysis, the use of positive reinforcement has been shown to motivate students to succeed both academically and behaviorally, and is of particular importance for SWE (Maag, 2001). Although it is commonly accepted by special educators that positive reinforcement can be motivating for particular students, not all schedules of reinforcement are equally effective for increasing levels of student motivation. Given the two broad categories of reinforcement schedules – continuous and intermittent – research indicates intermittent reinforcement is particularly effective in behavior modification, generalization, and maintenance of previously learned behaviors (Cooper, Heron, & Heward, 2007; Weisman & Clements, 1993). Intermittent reinforcement provides reinforcement after some behaviors, but not all. The unpredictability of reinforcement tends to increase occurrences of the desired student behavior. Neuroscience research can now offer neurophysiological explanations of the value of intermittent reinforcement, and can validate and confirm the use of this type of reinforcement for SWE.

Neuroscientists and biologists have long suspected the implication of dopamine in relation to human motivation; increased amounts of dopamine in the brain have been associated with increased levels of motivation in individuals (Depue & Collins, 1999; Purves, 2012). Additionally, the prospect of uncertain rewards (intermittent reinforcement) has been shown to increase levels of motivation, specifically related to learning games (Caillois, 1961; Hong et al., 2009). Researchers are currently studying how this knowledge can improve instructional approaches and increase levels of student engagement and motivation. For instance, Howard-Jones and Demetriou (2009) conducted several studies examining the influence of gaming uncertainty on student levels of motivation related to computer-based learning games. In this research, Howard-Jones and Demetriou demonstrated the effect of intermittent reinforcement (gaming chance) on levels of student motivation. Based upon their research, they hypothesized that human dopamine levels peak at a 50:50 chance to secure reinforcement. This finding holds significant implications for the deliberate consideration of reinforcement schedules of learning games. If learning games are developed based upon emerging understandings of dopamine, motivation, and chance, researchers have the potential to create learning environments that maximize student motivation, particularly for SWE.

Engagement. Effective teachers know how to engage their students. This is a fundamental principle of teaching and learning (Appleton, Christenson, & Furlong, 2008). Although teachers are provided with many strategies throughout their teacher preparation program for creating student engagement, many classrooms are filled with unengaged students. Why does this occur? There are many obvious reasons, including lack of teacher enthusiasm, unilateral instruction, or the inability of the students to see relevance or value in the lesson. However, an understanding of the reticular activating system (RAS) can help teachers understand and improve student engagement.

The RAS is a primitive network of cells located in the brain stem. It functions as an intake filter, screening sensory information, before it is sent to the upper regions of the brain. It is responsible for regulating levels of arousal, ranging from lethargy to hyperactivity. The RAS is directly affected by levels of stress. If an individual feels threatened, all sensory input is directed to the lower brain stem and the “fight, flight, or freeze” system is activated. Alternatively, if an individual is under-stimulated by their environment, they will not respond or engage with the provided sensory input, and neuronal input will not reach the cerebral cortex, hypothalamus, or thalamus. This holds significant implications for classroom instruction. If students interpret instruction as too difficult, they are likely to process the instructional stimuli as a threat, stress levels will rise, and the RAS will likely not send the sensory input on to the upper regions of the brain. The RAS is indicating to the student that they are in danger, and must focus on survival. Alternatively, if the work is too easy, the RAS will not take notice of the sensory input because it is not deemed relevant. These findings support Vygotsky's (1978) theory of proximal zones of development. Students needs to be provided with instruction that is within their range of comfort, but not too easy. Carol Ann Tomlinson (2011) has explored the function of the RAS and has argued that differentiation is effective when it considers the regulatory importance of the RAS.

Responsiveness to interventions. At the most basic level, special education research involves three steps: (a) collecting baseline data on a behavior or skill, (b) implementing an intervention targeting the selected behavior or skill, and (c) assessing whether the intervention had a positive effect on the selected behavior of skill (Mertens & McLaughlin, 2003). Simply stated, educational research involves collecting pre-assessment data, implementing an intervention, and collecting post-assessment data. Neuroscience research now offers special educators with a window into the neural processes related to the behaviors and skills that are the focus of their research interventions. Through the use of EEGs and fMRIs, researchers are able to examine the brain's plasticity in response to an academic or behavioral intervention. This added neurobiological information can enhance the ability of special educators to develop, implement, and evaluate efficacious interventions.

During the act of reading by typical students, neuroimaging studies reveal they demonstrate increased left-hemisphere engagement and decreased right-hemisphere engagement of the brain. Turkeltaub and colleagues (2003) postulated this is due to a transference of visual stimuli like letters and words from discrete percepts to categorical linguistic representations. Of significant import for special educators is that functional neuroimaging studies have revealed insights into the atypical brain function and connectivity present in individuals with dyslexia (Gabrieli, 2009). In general, individuals with dyslexia characteristically exhibit decreased activation in the left temporo-parietal and frontal regions when processing visually presented words, letters, or sentences (Eckert, 2003; Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008).

Although this information is noteworthy because it provides an increased understanding of the neurobiological causes of dyslexia, it also provides researchers with data useful for assessing the interventions for students with dyslexia. To date, several promising research studies have revealed brain plasticity correlated with effective interventions for dyslexia (Meyler et al., 2008; Shaywitz et al., 2004; Temple et al., 2003). Using neuroimaging techniques, successful dyslexia interventions have demonstrated increased activation or normalization of the left temporo-parietal and frontal regions, the mechanisms underlying reading development.

For example, Temple et al. (2003) conducted a study on the effectiveness of the Fast Forward language intervention for students with dyslexia. Fast Forward is a computer-based intervention that targets students' reading comprehension and oral language fluency validated as having medium to strong effects for alphabetics and comprehension by the What Works Clearinghouse. The study consisted of 20 students with dyslexia and 12 typically reading students (ages 8-12). The students with dyslexia were provided an eight-week training session with Fast Forword language. At the end of the intervention, assessment data indicated the experimental group made significant gains in word attack, rapid naming, oral language fluency, and reading comprehension. The researchers also conducted pre and post EEGs for both the experimental and control groups. The experimental group demonstrated increased hyperactivation of the left-temporo parietal lobe, the same region activated during phonological processing as the control group both pre and post intervention—thereby providing further support and a possible mechanism for the intervention's positive effects.

The use of neuroimaging techniques is not restricted to the study of interventions for learning disabilities like dyslexia. A growing amount of research is investigating the application of EEGs and fMRIs for the network of brain regions implicated in behavioral pathologies. Research in this area has focused predominantly on the development and assessment of effective interventions for ADHD (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Steinmann, Siniatchkin, Petermann, & Gerber, 2012; Sotnikova et al., 2012) For example, Hillman et al. (2014) conducted a randomized control trial that used EEGs to measure the effectiveness of an intervention to increase attention in students. The study participants included 221 children (ages 7-9). The experimental group participated in an exercise program called FIT Kids. The intervention duration was 9 months, and the students met for 2 hours after school. The intervention included 45 minutes of moderate to vigorous activity each session, along with a healthy snack, and structured games. At the end of the intervention, experimental participants demonstrated an increased aerobic fitness, increased ability to focus and ignore distractions, and improved ability to switch between instructional tasks with accuracy and speed. Using EEGs, the researchers also measured the P3 amplitude of both experimental and control groups. Measures of P3 amplitude demonstrate an individual's ability to process cognitive tasks related to executive function. Findings from the study revealed significant gains in P3 amplitude in the experimental group, but not in the control group. With time, these same techniques could and should be applied to the study of interventions for a variety of other disabilities, including autism, severe disabilities, and visual and hearing impairments.

Teacher perceptions. In order to improve school and community environments for SWE, researchers and educators should work to make "invisible" or "hidden" disabilities "visible." According to the Invisible Disabilities Association, people with hidden disabilities experience marked discrimination throughout their lives, in large part because their behavior does not match people's expectations. A small amount of research has been conducted on teachers' attitudes towards individuals with severe disabilities compared to individuals with mild (predominantly invisible) disabilities. The studies have demonstrated that teachers tend to have a more positive attitude towards individuals with more severe disabilities (Cook, 2001; Janney, Snell, Beers, & Raynes, 1995; Soodak, Podell, & Lehman, 1998). Students with physical and readily apparent exceptionalities tend to experience less discrimination than students with less obvious exceptionalities. However, neuroscience imaging can be an efficacious tool in improving teachers' attributions towards students with invisible exceptionalities by simply making their exceptionalities visible (e.g., EEGs of children with ADHD). The intersection of neuroscience and attribution theory can facilitate a more equitable and positive environment for students with invisible disabilities.

Attribution theory is an established cognate area in social psychology that provides a framework for understanding how people perceive and react to the behavior of others (Heider 1958; Weiner, 1985, 2012). Attribution theory maintains that an individual's perception of the cause of another person's behavior implicitly influences their perception and reaction to that behavior. Attribution theory considers three causal dimensions when examining beliefs about behavior: (a) locus (is the behavior caused by an internal or external source?), (b) controllability (is the individual able to control the behavior?), and (c) stability (is the behavior static or dynamic?). When undesirable behavior is perceived as being caused by external forces, out of the individual's control, and dynamic, others will react with sympathy and tolerance. However, if undesirable behavior is perceived as being caused by internal forces, within the person's control, and static, others tend to react with disgust and contempt (e.g., Weiner, 1993).

Attribution theory research has shown that people are much more tolerant of behavior when the cause is physiological (e.g., epilepsy, blindness, cerebral palsy) as opposed to behavioral (e.g., aggression, hyperactivity, addiction) (Wiener, 1993). Many teachers may experience this phenomenon when processing the behaviors of students with invisible disabilities (e.g., students with learning disabilities or students with emotional and behavioral disabilities). Students with invisible disabilities present teachers with challenging behaviors, yet physically they appear to be "typical" children. Thus, teachers may react in a negative and counterproductive fashion to these students because they may erroneously believe the behavior is (a) controllable, (b) intentional, and (c) static.

Attribution theory provides a framework for understanding teachers' perceptions of the behaviors of students with invisible disabilities. However, it does not provide a solution for rectifying the problem at hand. Recent findings in neuroscience can be used as a vehicle to alter teachers' perceptions of student behavior. Specifically, neuroscience can be applied to improve teachers' attributions towards students with hidden disabilities in (a) background knowledge, (b) physiological considerations, and (c) neural plasticity.

According to attribution research, individuals are more likely to respond in a positive, non-discriminatory fashion if they have background knowledge about the causes of the other person's behavior (Johnson & Fullwood, 2006; Wiener, 1985). In addition, the more familiar a person is with the causes of another person's behavior, the more sympathy and tolerance they will exhibit for the other person (Corrigan, Markowitz, Watson, Rowan, & Kubiak, 2003). Unfortunately, contemporary teacher preparation programs seldom provide teacher candidates with sufficient background information about the etiology of atypical behavior (Goswami, 2006; Dekker et al., 2012; Dubinsky, 2010; Tardif et al., 2015). In their research about teacher knowledge related to the neurobiology of behavior, Walker and Plomin (2005) discovered the majority of in-service teachers had very little awareness of the topic. Significantly, they also found that over 80% of the teachers surveyed said that if they were made aware of specific neurobiological contributors of a student's behavior they would incorporate this knowledge into their management and instruction.

In order to improve teachers' responses to students with hidden disabilities, they should be provided with more background knowledge about the causes of their behavior. A recent study by Sarver and colleagues (Sarver, Rapport, Kofler, Raiker, & Friedman,

2015) provides a strong argument for this case. In general, students with ADHD-combined type exhibit excessive motor activity in the classroom. This might include picking at erasers, tapping fingers on desks, bouncing legs up and down while seated, and other similar behaviors. These behaviors can annoy and frustrate teachers, and teachers usually work to diminish these behaviors.

Sarver and colleagues investigated the relationship between motor activity, attention, and performance among children with and without ADHD. During the study, they observed intraindividual motor differences in children and their level of attention and achievement. The study results indicated a positive correlation between motor activity and achievement in students with ADHD. For children without ADHD, they found a negative correlation between motor activity and performance. This suggests there may be a compensatory mechanism within children with ADHD whereby motor activity enhances cognition and attention. Neuroscience research indicates hypoactivation of the pre-frontal lobe in students with ADHD; persistent fidgeting is likely a physical manifestation of this neurological condition. This novel research demonstrates the capacity of neuroscience-informed research for opening new channels of understanding about hidden exceptionalities for teachers. If teachers are made aware of the etiology and function of specific behaviors (e.g., fidgeting), they may develop more positive approaches to the undesirable behavior.

As outlined above, *fundamental attribution error* (FAE) occurs when individuals are more likely to exhibit tolerance and patience towards another person if they perceive the cause of the person's behavior as physiological. Neuroscience can help ameliorate the debilitating effects of FAE by confirming that the causes of challenging behaviors *are* physiological. For instance, although teachers cannot see the neurobiological processes that contribute to the disruptive behaviors of EBD, they can be shown what these processes look like with neuroimaging techniques. This can be especially helpful for educating teachers about the etiology of ADHD. The physiological differences in the brain between children with ADHD and children without ADHD can clearly be seen in EEGs. If teachers are provided with this visual aid during their training, they will come to an understanding of the physiological pathomechanisms of ADHD. This can help them become more tolerant and patient with this student population.

This patience is also influenced by whether an individual believes another person's behavior is malleable. Neuroscience findings in the area of synaptic plasticity can be especially helpful in altering teachers' beliefs that student behavior is static. Teachers can be shown EEGs from intervention studies that visually depict synaptic change from pre to post intervention (e.g., Hillman, 2014). In addition, teachers can be taught about the principles of synaptic plasticity. A leading researcher in cognitive neuroscience and education at the University of Minnesota developed a teacher-training program about neuroscience called Brain U (Dubinsky, 2010). During the training, teachers learn about synaptic plasticity. The teachers were taught that in the process of learning, new neural connections are formed, and that the brain is remarkably capable of making new connections. The course focuses on training teachers about plasticity in order to challenge their perceptions of their students' potential.

Theoretical and Practical Barriers

Neuroscience holds significant promise for improving special education research and practice; however, many theoretical and practical barriers currently hinder these new developments. Many of the barriers that preclude a successful collaboration between neuroscience and education are rather obvious. The field of special education is governed by the principles, methods, and epistemologies of the social sciences, whereas the field of neuroscience is informed by the principles, methodologies, and epistemologies of the natural sciences. The theoretical and practical incongruity between these fields invariably poses barriers and challenges to effective collaboration among researchers in these fields. Special educators are trained to be practitioners, and their approaches are organized almost exclusively around behavioral paradigms, the nature of their work undeniably shaped by personal experience and contextual realities. Neuroscientists are trained to be quantitative researchers, and lack an awareness of the environmental milieu of the typical classroom, and practical pedagogical principles.

The goals and academic language of each field are fundamentally divergent, and unless a purposeful, concerted effort is made, it seems unlikely that professionals in these disparate fields will engage in meaningful dialogue. Educational psychology can serve as a mediating field between neuroscience and special education, as educational psychologists examine brain function in relation to cognition. However, the methodology employed by educational psychologists is still driven by observed behavioral patterns, and does not provide the detailed examination of neural activity that is proffered by researchers in neuroscience.

Over the past decade, the barriers to collaboration between neuroscience and education have been systematically articulated, researched, and explored by Paul Howard-Jones, an ardent advocate for the advancement of neuroeducation. A professor of neuroscience and education at the University of Bristol, he is also a member of the Centre for Mind and Brain in Educational and Social Contexts. His seminal text, *Introducing Neuroeducational Research: Neuroscience, Education, and the Brain from Contexts to Practice* (Howard-Jones, 2010), presents summary reports of seminar series convened to specifically examine collaborative frameworks for neuroscience and education, and the theoretical, practical, and strategic issues involved in such a feat. Each seminar event was designed to yield the insights and opinions of a transdisciplinary group of professionals, including teachers, psychologists, neuroscientists, and policymakers. The seminar discussions generated several key findings: (a) although neuroeducation holds promise for improving student outcomes, findings from neuroscience are rarely directly applicable in the classroom; (b) all parties involved in the collaboration need to be wary of promoting neuromyths and pseudoscience; (c) professional aims differ across participating fields; (d) clear communication is absolutely essential to ensure scientifically valid and accessible information about research and concepts involving the brain for educators; and (e) it is critical that both educators and scientists are active members in this collaboration.

In their discussion of the development of the field of neuroeducation, Devonshire and Dommett (2010) also emphasized the critical importance of effective and precise communication. They asserted that neuroscientists need to be trained in science communication, so their work is accessible to those outside of their field. Additionally, Devonshire and Dommett suggested that neuroscientists should provide separate basic reports based on their articles published in peer-reviewed research journals. They also recommended that educators receive basic training in neuroscience so they are able to be critical and discerning consumers of neuroscience research and be able to discriminate between neuromyths and scientifically valid concepts appropriate for use in the classroom. However, in their discussion of barriers to collaboration, Ansari and Coch (2006) suggested that researchers from both fields are reluctant to change established practices, and there is insufficient funding to foster effective collaboration.

Although opening channels of communication between scholars in the two separate fields of neuroscience and education has been emphasized, it has also been suggested that a hybrid professional – a scholar trained in both neuroscience and education — might be the most efficacious approach to marry the separate fields of neuroscience and education (Howard-Jones, 2010). Jocelyn Fuller and James Glendening (1985) called these professionals neuro-educators. Although the development of this unique professional has yet to come to fruition, substantial progress has been made in forging the requisite interdisciplinary partnerships needed to further collaborative efforts in neuroeducation.

Unfortunately, the lack of understanding and communication between the separate fields of neuroscience and education has created a climate rife with pseudoscientific theories. Many researchers have written position pieces lamenting the existence and proliferation of neuromyths (e.g., Ansari & Coch, 2006; Geake, 2008; Goswami, 2006; Lindell & Kidd, 2011; Organisation for Economic Co-operation and Development, 2002; Pasquinelli, 2013). This scholarship has done much to expose and problematize neuromyths, and establish a foundation for extant research studies on neuromyths presented in the next section.

Extant Research Studies on Neuromyths

Although several publications have emphasized the pervasiveness of neuromyths within educational practice, few studies have directly investigated the prevalence of specific neuromyths among teachers. Until fairly recently, evidence regarding the ubiquity of neuromyths amidst educators was primarily anecdotal. This gap in the research is problematic for many reasons. On the most elemental level, it is difficult to appreciate or address the supposed deleterious effects of neuromyths in the absence of data indicating their existence. In order for researchers and teacher educators to commit to addressing the insidiousness of neuromyths, there first must be objective evidence these myths are indeed prevalent among teachers. Additionally, to strategically target the most prevalent pseudoscientific beliefs about the brain and learning, it is necessary to identify the most commonly held educational neuromyths. It is also necessary to study teachers' general knowledge about brain structure and function to develop curriculum to provide training for teachers in the key cognitive principles of learning and behavior that they misunderstand. Simply stated, it is necessary to study teachers' baseline beliefs and practices to develop effective teacher training curriculum. Teacher preparation programs should improve their existing curricula to better prepare teachers to be critical of ideas and programs that claim to have a basis in neuroscience, and improve their overall instructional practice and decision-making.

Considering the pressing need for research studies on teachers and neuromyths, it is encouraging to note that five studies on this topic were published in 2015 (Deligiannidi & Howard-Jones, 2015; Gleichgerrcht et al., 2015; Karakus et al., 2015; Pei et al., 2015; Tardif et al., 2015). This is a significant increase to the aggregate output of research on this issue. Prior to 2015, there were a mere two research studies on neuromyths and education published in peer-reviewed journals (Dekker et al., 2012; Rato et al., 2013). The proliferation of research studies on neuromyths is indicative of the burgeoning interest in the field of neuroeducation, and perhaps bolstered by the growing awareness of the general public's penchant to uncritically embrace morsels of pseudoscience (Weisberg, Keil, Goodstein, Rawson, & Gray, 2009). Ostensibly, these new research studies have the potential to increase the legitimacy of the role of neuroscience in special education, and can provide a foundation upon which the field can flourish.

The extant research studies on teachers and neuromyths exhibit marked similarities across many domains, including purpose, measures, procedures and study outcomes. Additionally, most of the studies sought to determine teachers' beliefs in three long-standing, questionable educational theories: (a) hemispheric dominance, (b) learning styles, and (c) Brain Gym® (also referred to as perceptual motor training). Five of the seven research studies used variations of one of two developed survey instruments for measuring teachers' knowledge of the brain and the prevalence of neuromyths amongst educators. Most of the researchers indicated they used existing surveys to facilitate across-studies comparisons of the research findings. Each of the research studies focused on teachers from discrete geographic areas, including the United Kingdom and the Netherlands, Latin America, Greece, East China, Turkey, Switzerland, and Portugal. To date, no research study has explored the prevalence of neuromyths among in-service and pre-service teachers in the United States. The following sections will provide an analysis of key components of the extant research studies.

Research Agenda

At first glance, the systematic study of neuromyths may appear a somewhat peculiar or immaterial endeavor. However, once situated within the current commercial and academic activity surrounding neuroscience and education, the importance of this research agenda becomes apparent. First, the application of cognitive neuroscience to educational practice continues to increase at a steady pace both in the popular press and among educational research articles. Once an endeavor unknown to most neuroscientists and educators, efforts in the past decade by government agencies, professional organizations, university programs, and commercial enterprises have solidified the legitimacy of the field of neuroeducation and have expanded its scope and influence within educational research (Gleichgerrcht et al., 2015; Pei et al., 2015). It is becoming apparent that this field of study is not a passing fad (Carew & Magsamen, 2010; Schwartz, 2015; Sousa, 2014). In response to this phenomenon, scholars have asserted it is necessary to carefully consider the manner in which neuroscience data is being received and applied within educational settings. This general consideration appears to guide the current research on neuromyths and is befitting the inherent complexities of a merger between neuroscience and education.

The difficulties in developing a conceptual framework to facilitate the meaningful application of neuroscience within education contributes to the creation and dissemination of neuromyths. This particular problem is mentioned throughout the current research on neuromyths. Tardif et al. (2015) introduced their study with an advisory about the difficulties of direct applications of neuroscience to the classroom. In the introduction to their study on neuromyths, Gleichgerrcht and colleagues (2015) problematized the ambitious objective of forging a collaboration between neuroscience and education. Other authors have suggested neuromyths thrive in the gaps created by miscommunication between neuroscientists and teachers (Karakus et al., 2015; Rato et al., 2013) Additionally, Pei et al. (2015) asserted neuromyths are disseminated among teachers via commercial educational materials, which misrepresent neuroscience and peddle pseudoscience as legitimate brain-based education programs.

Another broad objective of extant research on neuromyths appears to simply represent a response to public demand. Over the past decade, the increasing interest in brain structure and function has created a climate ripe for the proliferation of neuromyths. If educators were not interested in the neuroscience and education, the deleterious effects of neuromyths would not be such a pressing issue. More than half of the extant research studies on neuromyths discuss the extensive interest among teachers in the application of neuroscience to educational practice (Dekker et al., 2012; Gleichgerrcht et al., 2015; Karakus et al., 2015; Tardif et al., 2015). Their assertions are supported by prior research conducted on teachers' perceptions and interest in neuroscience (Bartoszeck & Bartoszeck, 2012; Howard-Jones, Franey, Mashmoushi, & Liao, 2009; Pickering & Howard-Jones, 2007; Serpati & Loughan, 2012). Current research on neuromyths acknowledges educators' desire to learn more about neuroscience, and by systematically investigating the prevalence and predictors of neuromyths provides critical data needed to improve neuroscience literacy in education.

Specific Research Purposes

There are many similarities in purpose across existing studies on neuromyths. All of the studies explicitly sought to measure teachers' beliefs in common educational neuromyths. Of significance, all of the studies attempted to measure teachers' beliefs in three popular neuromyths: (a) hemispheric dominance, (b) modality dominance, and (c) perceptual motor training (known commercially as Brain Gym®). Additionally, all but one study (Tardif et al., 2015) surveyed participants on their general knowledge of brain structure and function. The belief in genetic determinism was explicitly explored in three studies (Dekker et al., 2012; Deligiannidi & Howard-Jones, 2015; Pei et al., 2015). Researchers were also interested in the sources of participants' information about the brain. All but two studies requested participants to identify their specific medium for learning about the brain (e.g., college course work, teaching training, colleague, friend, television, newspaper, internet). Most of the research studies, with the exception of Dekker and colleagues (2012), sought to conduct a cross-cultural/geographic comparison of the responses of their study participants to prior studies on neuromyths. Authors of the studies conducted in Greece, East China, and Portugal provided discussions of specific cultural influences on the beliefs in neuromyths within their education systems. Lastly, two studies sought to determine how teachers' beliefs in neuromyths affected instructional decisions in the classroom (Rato et al., 2013; Tardif et al., 2015).

Procedures

Remarkable similarities exist across procedures among the studies. Six of the seven studies include both primary and secondary teachers in their samples. The Swiss study (Tardif et al., 2015) included pre-service teachers and university professors in their study. All of the studies used a survey research design; most surveys were completed electronically. Six of the seven research studies used one of two surveys developed from information produced by the Brain and Learning Project of the OECD. This working group identified common neuromyths within education. The two most frequently used surveys in extant studies on neuromyths (Dekker et al., 2012; Howard-Jones et al., 2009) were developed using the most ubiquitous neuromyths identified by OECD.

Outcomes

In this section I examine findings from extant research on neuromyths across the (a) prevalence of neuromyths and general knowledge of the brain, learning, and behavior; (b) genetic determinism and neural plasticity; (c) predictors of neuromyth acceptance; (d) influence on decision making; (e) cultural considerations; and (f) limitations.

Prevalence of neuromyths and general knowledge of the brain learning and behavior. Across all studies, participants exhibited a marked belief in most neuromyths. The studies of teachers in the UK and Netherlands (Dekker et al., 2012), Latin America (Gleichgerrcht et al., 2015), and Turkey (Karakus et al., 2015) used the same survey (Dekker et al., 2012). Their responses indicated a belief in neuromyths (as indicated by checking "correct" on the survey to a neuromyth assertion) as follows: UK and Netherlands, 49%; Latin America, 51%; and Turkey, 53%. With regards to general information about the brain, participants in the UK and Netherlands responded with 70% accuracy. Latin America participants responded incorrectly to more than 50% of probes about brain structure and function. The majority of Turkish participants responded incorrectly to probes about general information about the brain. Participants across all three studies indicated strong beliefs in three ubiquitous neuromyths: (a) hemispheric dominance, (b) modality dominance, and (c) perceptual motor training. Over 80% of participants in the UK and Netherlands study supported all three of these myths. A remarkable 97% of Latin American participants supported learning modalities, and 71% believed in hemispheric dominance. Similar results were found in the Turkish study.

The studies of teachers in Greece (Deligiannidi & Howard-Jones, 2015) and East China (Pei et al., 2015) utilized the same survey (Howard-Jones et al., 2009). Consistent with the findings from studies in the UK and Netherlands, Latin America, and Turkey, participants from Greece and East China demonstrated strong beliefs in most neuromyths. Seventy one percent of Greek teachers supported myths related to hemispheric dominance, 97% supported myths related to learning modalities, and 56 % supported myths related to perceptual motor training. Seventy one percent of participants from East China supported myths related to hemispheric dominance, 97% supported myths related to learning modalities, and 66% supported myths related to perceptual motor training.

The Swiss study differed from other studies in that their survey focused solely on these common myths, forgoing probes related to other neuromyths and general knowledge about the brain. The participants of this study indicated strong beliefs in hemispheric dominance, learning modalities, and perceptual motor training; teachers supported these myths 85%, 96%, and 79% respectively (Tardif et al., 2015). The survey used in the Portuguese study required participants to identify myths and facts across a range of topics related to brain function and educational interventions. Similar to the related studies on neuromyths, participants did poorly identifying myths related to hemispheric dominance, learning modalities, and perceptual motor training; less than 20% of the participants recognized these myths (Rato et al., 2013). Table 1 shows the top neuromyth findings for each study.

Table 1

Top neuromyths across studies, by percentage of participants

Study	Participants	Measures	Findings
Dekker, Lee, Howard-Jones, & Jolles, 2012 (UK & Netherlands)	N=242 K-12 teachers	32-item instrument to assess neuromyths and general brain knowledge	89% support hemispheric dominance 95% support learning modalities 71% support perceptual motor training
Deligiannidi, & Howard-Jones, 2015 (Greece)	N=217 K-12 teachers	40-item instrument to assess teachers' education neuroscience literacy and general brain knowledge	71% support hemispheric dominance 97% support learning modalities 56% support perceptual motor training
Gleichgerrcht, Luttges, Salvarezza, & Campos, 2015 (Latin America)	N=3,451 K-12 teachers & education professors	32-item instrument to assess neuromyths and general brain knowledge	72% support hemispheric dominance 90% support learning modalities 83% support perceptual motor training
Howard-Jones, Zhang, Liu, & Jin, 2015 (China)	N=238 K-12 teachers	40-item instrument to assess teachers' education neuroscience literacy and general brain knowledge	71% support hemispheric dominance 97% support learning modalities 66% support perceptual motor training
Karakus, Howard-Jones, & Jay, 2015 (Turkey)	N=278 K-12 teachers	32-item instrument to assess neuromyths and general brain knowledge	79% support hemispheric dominance 97% support learning modalities 57% support perceptual motor training
Rato, Abreu, & Castro-Caldas, 2013 (Portugal)	N=538 K-12 teachers	Closed and open-ended instrument to assess perceptions of neuromyths	Over 50% of participants support hemispheric dominance and modality dominance
Tardif, Doudin, & Meylan, 2015 (Switzerland)	N=283 Pre and in-service teachers	18-item instrument to assess perceptions of learning modalities, Brain Gym, and hemispheric dominance	83% support hemispheric dominance 85% support learning modalities 79% perceptual motor training

Genetic determinism and neural plasticity. Researchers in four studies evaluated teachers' ideas about the role of genetics, biology, and environment in shaping learning and behavioral outcomes for their students. In the UK/Netherlands teachers attributed 28% of learning to genetics, 38% to home environment, and 27% to school environment. Greek teachers attributed 27% of learning to genetics, 33% to home environment, and 36% to school environment (Deligiannidi & Howard-Jones, 2015). In the Turkish study, only 40 % of the teachers supported the concept of neural plasticity, the ability of the brain to create new neural connections via behavior and environmental stimuli (Karakus et al., 2014). In the study of East Chinese teachers, only 50% of the teachers indicated a belief in neural plasticity (Howard-Jones et al., 2015). Although replication studies should be conducted to further explore this data, at first glance it is alarming. Theories of neural plasticity have been associated with academic growth, knowledge formation, and self-concept (Blackwell, Trzesniewski, & Dweck, 2007). It is worrisome that many teachers fail to recognize the importance and function of neuroplasticity. This is problematic as teachers may unwittingly set low expectations for their low-performing and at-risk students – particularly students with exceptionalities – precluding optimal academic and behavioral growth.

Predictors. Most of the research studies collected participants' demographic information to identify potential predictors of the participants' general knowledge of the brain and recognition of neuromyths. Interestingly, across all studies, there was no statistically significant difference in performance when accounting for teacher experience or grade-level placement. The authors of the Latin America research study reported that professors of higher education had higher rates of correct responses to general statements about brain structure and function (not neuromyth statements) when compared to participants of all other education levels (Gleichgerrcht et al., 2015). However, this outcome needs to be studied more thoroughly as it was demonstrated in only one study, and professors comprised only 8.4% of the entire study sample.

Across the studies, researchers prompted participants to share their sources for information about the brain. Teacher responses included popular science journals, colleagues, friends, newspapers, the Internet, college courses, in-service trainings, and the media. A significant amount of participants identified the popular media and press as their primary sources of information. This is obviously problematic as general science facts and findings are frequently distorted in the popular press (Beck, 2010). However, it was encouraging to note that both the Latin American study (Gleichgerrcht et al., 2015)and the UK/Netherlands study (Dekker et al., 2012) found that teachers of all levels who indicated they read general information about science and primary scientific literature performed better overall on general questions about brain structure and function. This finding should be researched further to gather more support; future research should also identify which specific science journals and primary scientific literature teachers most commonly read.

An interesting finding that warrants future exploration emerged from the Latin American study and the UK/Netherlands study. Both studies found a positive correlation between teachers' beliefs in neuromyths and strong general knowledge of the brain. This finding appears counterintuitive. Although it may seem that the more general knowledge a person has about brain structure and function, the better equipped they are to detect neuromyths, but this was not the case. Participants with more background knowledge did worse at identifying neuromyths. The authors did not provide any meaningful discussion about possible contributors to this phenomenon. However, this finding intimates the need for research dedicated to create effective curriculum to assist teachers in applying their general knowledge about the brain to the complexities of dismantling myths surrounding the brain and education.

Influence on practice. Although all of the research studies explored the prevalence of neuromyths among teachers, only one of the studies (Tardif, Doudin, & Meylan, 2015) investigated whether teacher beliefs in neuromyths and decision-making. This is a fundamentally important construct that should not be overlooked. It is critical to identify teachers' beliefs in neuromyths, but it is of much more practical significance to explore the manner in which such beliefs impact classroom instruction. Tardif and colleagues (2015) first queried participants about their beliefs in three common neuromyths: hemispheric dominance, learning modalities, and Brain Gym® Participants were instructed to indicate whether these myths have a basis in brain research. Responses indicated that 83% of teachers believed hemispheric dominance was supported by research, 85% believed learning modalities were supported by research, and 79% believed Brain Gym® was supported by research. The researchers then queried participants about their use of these practices. Responses indicated that 27% of teachers used or intended to use programs founded on hemispheric dominance, 80% of teachers used or intended to use practices derived from the theory of learning modalities, and 65% of teachers used or intended to use the Brain Gym® curriculum.

This information is valuable in ascertaining the influence neuromyths may have on classroom practice. When analyzing specific data, it is disconcerting to note that 80%

of teachers use or would like to use practices based on learning modalities, and 65% of teachers use or intend to use the Brain Gym® curriculum. This research study provides much needed insight into the dissemination of questionable programs in the classroom. It would be a prudent measure for future research on neuromyths to consider including this important construct. As concerns about neuromyths proliferate, researchers need targeted information about the practical implications of neuromyths. This type of information is invaluable in developing teacher-training curriculum. Furthermore, this approach highlights the need to include administrators in this survey research, as they are the individuals who tend to control the curriculum and instructional approaches mandated in their schools.

Cultural considerations. Most of the research studies sought to compare their outcomes across teachers in the various countries surveyed. After analyzing the data, the outcomes related to knowledge of the brain and belief in neuromyths appear generally consistent across countries. However, some of the studies attempted to isolate idiosyncratic cultural phenomenon to examine in relation to prevalent neuromyths. For instance, the Portuguese study suggested that teachers may be particularly susceptible to the myths surrounding vitamin supplements and academic achievement due to an aggressive public service campaign in the 1970s that stressed the importance of bio supplements. The Greek study (Deligiannidi & Howard-Jones, 2015) suggested their teachers possess a more complex construction of the mind-brain relationship than teachers from other countries due to the strong sense of religiosity among its citizenship who are overwhelmingly Christian Orthodox. Lastly, in the East Chinese study (Pei et al., 2015) researchers found differences in their teachers' attitudes towards attention and engagement when compared to other studies. The authors surmised this may be reflective of differences between Eastern and Western notions of attention, claiming Chinese have a skeptical perception of the Western emphasis placed on multi-tasking. In support of this assertion, the authors cited a common Chinese saying, "a man cannot spin and weave at the same time" (p. 3686).

Limitations. There are several limitations to the extant research on neuromyths that I address in the present study. Interestingly, to date, there have been no known studies on the prevalence of neuromyths among educators in the United States. As prior research suggests, neuromyths are commonly believed by teachers across the globe. It is necessary to determine whether educators in the United States also tend to believe in similar neuromyths. There are many policy and practice implications if the data collected reveals this phenomenon. Additionally, none of the extant research targeted special educators. I believe it is important to sample this population as they are the professionals who most commonly work with students who experience atypical development, and this population is most frequently addressed within neuroscience research. Lastly, prior research has not specifically targeted the influence of neuromyths on instructional decision-making. I designed a mixed methods study to address these specific limitations as outlined in the following chapter.

CHAPTER 3

METHOD

As outlined in Chapter One and Chapter Two, neuromyths in education are both prevalent and problematic. To date, no research has specifically investigated the perceptions of neuromyths among pre-service teachers in the United States. Moreover, no research has explored the potential impact of neuromyths on instructional decisions. In this chapter I provide a justification and description of the selected research design of this study. I also review the following methodological elements of the study: (a) participants, (b) instrumentation, (c) pilot study, (d) procedures, and (e) data analysis.

Purpose of Study and Research Questions

The purpose of this study was to investigate the pervasiveness of neuromyths among pre-service special education teachers in the United States and to explore how neuromyths may influence instructional decisions. The specific research questions were:

1. What are pre-service teachers' perceptions of educational neuromyths and general knowledge of the brain, learning, and behavior?
2. What is the self-reported likelihood of pre-service teachers to implement an array of instructional practices (effective and ineffective)?
3. Is there a relationship between perceptions of neuromyths and likelihood to implement corresponding instructional practices?
4. Is there a relationship between demographic factors and beliefs in educational neuromyths and general knowledge of the brain?

5. What are participants' perceived levels of preparedness in educationally relevant neuroscience literacy, what is their interest in learning about this topic, and what sources do they use for information about this topic?

Research Design

This study employed a mixed-methods explanatory research design to investigate the specific research questions. Mixed methods research combines the attributes and strengths of qualitative and quantitative research in a single study. Most scholars attribute the genesis of mixed methods to the work of Campbell and Fiske (1959). Their foundational article introduced the concept of triangulation, and encouraged the use of multiple methods to validate research data. Their seminal work was embraced and notably advanced by Webb, Campbell, Schwartz, and Sechrest (1966); Denzin (1978); Jick (1979); Greene, Caracelli, and Graham (1989); and Creswell (1994).

Over time, the use of mixed methods steadily increased in popularity among social science researchers, leading to the publication of *The Handbook of Mixed Methods in the Social & Behavioral Sciences* (Tashakkori & Teddlie, 2003). Several scholarly journals are now dedicated to mixed methods research, including the *Journal of Mixed Methods Research*, *Quality and Quantity*, and *Field Methods*. In contemporary research practice, mixed methods research is considered a legitimate major research approach with distinct advantages over quantitative and qualitative research designs used in isolation (Creswell & Clark, 2007; Johnson, Onwuegbuzie, & Turner, 2007; Klingner & Boardman, 2011).

Mixed methods research is commonly considered to be a *practically* advantageous research design; pragmatism is the underlying philosophical constitution of the mixed methods approach. The work of pragmatists such as Peirce, James, Mead, and Dewey provide the theoretical framework for this research methodology. Pragmatists believe methodological pluralism enables researchers to most effectively investigate their research questions. Mixed methods research strives to consider multiple perspectives, data sources, theories, approaches, and concepts to best answer selected research questions (Creswell, 2007). Johnson and Turner described this as the *fundamental principle of mixed research* (2003). This principle advises researchers to:

> Thoughtfully and strategically mix or combine qualitative and quantitative research methods, approaches, procedures, concepts, and other paradigm characteristics in a way that produces an overall design with multiple (divergent and convergent) and complementary strengths (broadly viewed) and nonoverlapping weaknesses. (p. 7)

Mixed methods researchers believe this methodological pluralism can yield more robust research findings compared to traditional quantitative or qualitative methods (Johnson & Onwuegbuzie, 2004).

There are many commonly accepted benefits of mixed methods research. In general, mixed methods studies can produce data of substantive depth due to the inclusion of both qualitative and quantitative forms of inquiry. Additionally, a mixed methods design provides researchers with the ability to corroborate their findings across data sources, improving the overall validity of the research study. In an explanatory article on the characteristics and benefits of mixed methods (Johnson, Onwueqzbie, & Turner, 2007), the authors reviewed the most commonly cited benefits of mixed methods according to current leading scholars in mixed methods research. Their review revealed that many researchers believe mixed methods designs yield dynamic and robust research data, and that the triangulation of data, theory, and/or methods provides more comprehensive and valid findings than other types of research designs.

Mixed methods can be an efficacious research method, but the design must be intentional, deliberate, and driven by specific research goals. Effective and rigorous mixed methods designs do not arbitrarily couple quantitative and qualitative methods. Instead, the designs should systematically incorporate components of both methods with attention given to the sequence of data collection, whether priority is given to quantitative or qualitative methods, and the integration and analysis of data. There are a variety of established mixed methods design strategies.

As indicated previously, this study employed a sequential explanatory design to address the specific goals and research questions. This approach is characterized by the collection and analysis of quantitative data followed by the collection and analysis of qualitative data. Some of the research questions of this study were best investigated using quantitative survey methodology (e.g., participants' beliefs in neuromyths and their general knowledge about the brain, learning and behavior). However, in order to fully address all research questions of this study, to gather additional information about participants' perspectives and beliefs about neuroscience and education, and to help explain the quantitative data, it was necessary to follow the quantitative data collection with a qualitative component (i.e., semi-structured individual interviews). The integration of the quantitative data analysis, coupled with the qualitative interview findings provided a robust picture of pre-service teachers' current perspectives of neuromyths as they relate to instructional practice.

Participants

In this study I collected data from a purposive convenience sample. The purpose of this study was to assess special education pre-service teachers' perceptions of neuromyths and their influence on instructional decisions, accordingly I recruited participants who met this criteria. My sample included pre-service initial licensure teachers in both special education programs and dual preparation programs (47.1% of participants were in special education programs and 52.9% were in dual preparation programs [involving training in special education and general education]).

Another goal of this study was to secure a nationally representative sample. This would allow for comparisons to extant studies on specific regions/countries, and provide information about trends in teacher education programs across the United States. Toward this end, I solicited participation from universities and colleges from all of the geographic regions identified by the United States Census Bureau: Northeast, Midwest, South, and West. Ideally, I would have liked to secure participants from all of these regions. However, I was unable to secure any participants from the Northeast. Table 2 presents the number of participants included from each state.

Table 2

Survey participants by state (N=131)

State	Number	Participants as total %
Kentucky	40	30.5
Ohio	37	28.2
Hawaii	34	26.0
Georgia	6	4.6
Illinois	4	3.1
Virginia	4	3.1
Alabama	1	0.9
Unspecified	5	3.8

Instrumentation

The Organization for Economic Cooperation and Development (OECD) is an international consortium comprised of 35 member countries that develops and promotes policies to improve the social and economic well being of people around the globe. The OECD has been in existence for nearly 70 years and regularly publishes books, working papers, statistics, and reports that highlight best practices to address common global economic and social problems. The Center for Educational Research and Innovation (CERI) is a research unit within the OECD. In 1999, CERI launched the "Learning Sciences and Brain Research Project." This project brought together experts from the fields of neuroscience and education to discuss emerging neuroscientific research related to learning and development. In 2002, OECD published a synthesis of the project findings, entitled *Understanding the Brain: Towards a New Learning Science.* Among other issues related to cognitive neuroscience, the publication included a list of the most common and neuromyths identified by leading scholars across neuroscience and education (see Appendix B).

In 2012, Dekker and colleagues published a research study on the prevalence of neuromyths among teachers in the Netherlands and the United Kingdom. For this study, the researchers developed a survey instrument based upon the neuromyths identified by OECD in 2002. The 32-item survey was comprised of 12 neuromyth statements and 20 general statements about the brain, learning, and development. For each statement, respondents could select one of three answers: "correct," "incorrect," and "do not know." The presentation order of the statements (neuromyth or general statement about brain knowledge) was randomized. Dependent variables in the study were the percentage of “incorrect” answers to neuromyth statements, and percentage “correct” responses to general assertions about the brain.

This survey instrument has been used in two other research studies. Karakus et al. (2014) used the same survey to study misconceptions about learning and the brain among Turkish teachers. Gleichgerrcht and colleagues (2015) employed the survey to evaluate the prevalence of neuromyths among teachers in Latin America. Additionally, three other research studies that focused on the prevalence of neuromyths among in-service and pre-service teachers have used a similar survey instrument (Deligiannidi & Howard-Jones, 2014; Pei et al., 2014; Rato et al., 2013). Although there is variation among the surveys used in these three studies, all of the instruments were developed using the neuromyths defined by OECD in 2002. Significantly, the neuromyths identified by OECD formed the basis for the survey instruments used in 6 out of the seven 7 extant research studies on neuromyths. There appears to be a general consensus among researchers about the validity and significance of the list of OECD neuromyths.

For this study, I used the survey instrument developed by Dekker and colleagues (2012). There are many advantages to using this survey. The neuromyths selected for inclusion in the survey have been thoroughly vetted and researched by leading experts in the areas of neuroscience and education. Additionally, although this list of neuromyths was comprised in 2002, it remains salient for contemporary educators. This is demonstrated by its use in three recent neuromyth studies published in 2015 (Deligiannidi & Howard-Jones, 2015; Gleichgerrcht et al., 2015; Karakus et al., 2015; Pei et al., 2015). Using this survey instrument also enables me to compare data from United States participants to data from other countries.

In order to address all of the research questions of this present study, I added an additional section to the existing survey. One goal of this study was to investigate participants' likelihood to implement instructional practices (ranging from ineffective to effective). This added survey component provided the opportunity to gather this type of data. Similar to a study conducted by Burns and Ysseldyke (2009), I created a list of practices (effective, highly effective, and with no empirical support) and prompted participants to rate their likelihood of implementing each practice. These data were also allowed for examining correlations between beliefs in neuromyths and self-reported likelihood to implement effective vs. ineffective practices. Additionally, it enabled me to investigate correlations between demographics and beliefs or practices. See Appendix C for the final survey instrument.

None of the neuromyth studies listed above examined reliability and validity of the survey instrument based upon the OECD list of neuromyths. However, the content validity of the survey is supported by the rigorous vetting method used by the OECD expert panel in the process of publishing *Understanding the Brain: Towards a New Learning Science*. I also addressed the reliability of the instrument prior to study implementation. Because there were no published reliability measures for the scale, I conducted a test-retest reliability study with a group of 31 undergraduate students enrolled in a dual preparation (special education and elementary education) at University of Hawaii. I administered the survey to the group of students twice, with an interval of one month between each administration. The test-retest reliability coefficient was .67. This is considered to be an acceptable reliability coefficient, but is on the lower level of acceptable reliability (Davidshoffer & Murphy, 2005).

Semi-Structured Interviews

In addition to collecting quantitative survey data, I also conducted semi-structured interviews with six study participants. I elected to develop interview prompts prior to the interviews in order to obtain the specific strands of information I needed to address my research questions. Semi-structured interviews are effective when you only have one chance to interview your study participants (Bernard, 1988). When developing the questions for my semi-structured interviews, and in preparing for the actual interviews, my process was guided by the text, *Mastering the Semi-Structured Interview and Beyond* (Galletta, 2013). See Appendix D for my interview prompts.

My interview prompts were developed based upon the purpose of my research. Prior research simply explored the existence of neuromyth beliefs among participants. For this study, I wanted to gather more information about the foundations of participants' beliefs in neuromyths and their rationale for potentially using instructional practices based upon neuromyths in the classroom. For instance, why did participants believe in a specific neuromyth? Additionally, if they believed in neuromyths, what informed their beliefs, and more importantly, how would they translate these beliefs to the classroom? The desire for this knowledge guided the development of the semi-structured interview questions. The questions were also developed based upon participants' answers to the survey instrument.

Procedures

As stated previously, this study used a convenience sample. In order to obtain study participants, I contacted deans, professors, and instructors at universities and colleges across the country to invite them to participate in the study by administering the survey to their students. In total, I contacted more than 40 individuals. However, it was difficult to track the number of individuals who received invitations to participate in my survey. Some of the individuals I contacted forwarded my email to colleagues and associates they thought might be able to assist in the project. I was not always informed of who was contacted during this process, and this made it difficult to calculate an accurate response rate. Most deans did not respond to my inquiries, and ultimately, the individuals that participated in the project were either people I knew, or who colleagues put me in contact with for the purpose of this project. In total, I had regular contact (approximately 3 to 4 email correspondences) about administering the survey with 16 teacher educators.

In efforts to secure an appropriate response rate, I used the research-based strategies developed by Baruch and Holtom (2008). These strategies include careful survey design, pre-notification of survey, ample response opportunities, manageable survey length, effective communication of survey importance, and provision of survey feedback. I sent out my initial invitation to participate in the study via email; see Appendix E for initial invitation. If a teacher educator responded to the invitation and agreed to participate in the survey, I then sent them an email containing the link to the survey. The survey was housed on Survey Monkey, an online survey software and questionnaire tool. The survey link provided the participants with the project description, the informed consent form, and the survey instrument.

I requested that participating teacher educators require their students to complete the survey while they were physically sitting in class. However, several of the teacher educators who participated in the project told me that they sent the survey link to their students for them to complete at a time of their convenience. I also requested that all participating teacher educators notify me of the number of students in their course(s) so I could calculate survey response rate. Based upon the information provided to me, my survey response rate was 51%.

The final survey question asked participants to indicate if they were willing to participate in a follow-up interview and to provide their email contact information. Of the 131 total survey participants, 33 individuals indicated they were willing to participate in an interview. I contacted all 33 individuals via email and six individuals responded and agreed to participate in the interviews. Three of the interview participants were from the West region, two participants were from the Midwest region, and one participant was from the South region. Four of the six participants were completing a special education initial licensure program, and two were completing a dual preparation initial licensure program. The interviews were guided by the semi-structured interview questions previously described (Appendix D). I based the interview discussions on the semi-structured interview prompts, but would include follow-up ancillary questions when appropriate. I conducted the interviews on Collaborate for ease of recording and transcription. Interview lengths ranged from approximately thirty to forty-five minutes.

The time and date for the interviews were selected based upon the convenience of the participants.

Data Analysis

As this was a mixed methods study, I analyzed both quantitative data and qualitative data. I used the Statistical Package for the Social Sciences (SPSS, version 22.0) to analyze the quantitative data. For all quantitative analysis, a threshold of $\alpha = .05$ was used for determining statistical significance. I ran descriptive statistics to calculate frequencies, percentages, means, ranges, and standard deviations for participants' responses. I calculated the percentage of correct responses to general assertions about the brain, percentages of beliefs in neuromyths, and likelihood to implement a variety of instructional practices. I conducted correlation analyses to examine potential relationships between perceptions of neuromyths, likelihood to implement specific instructional practices, and specific demographic factors. Additionally, I ran Krusakal-Wallis non-parametrics to analyze likelihood to implement instructional practices.

To assess the qualitative data, I employed the framework approach to qualitative data analysis developed by Richie and Spence (1994). This process involves: (a) becoming familiar with the text, (b) identifying main themes, (c) indexing themes, (d) coding themes, and (e) mapping and charting themes for interpretive purposes. The qualitative data provided by participants enhanced the quantitative data, providing insight into their beliefs about neuromyths and producing data instrumental for exploring the influence of neuromyths on decision-making and potential instructional influences.

For purposes of validity and reliability, I used common strategies for analyzing qualitative data. One advantage of the mixed method design of this study was the ability to triangulate the quantitative and qualitative data to check for reliability and validity. I gathered both quantitative and qualitative responses to address the main research questions. I compared participants' qualitative and quantitative responses to check for disconfirming evidence and discrepancies. Additionally, I triangulated data across participants to bolster the reliability and validity of the survey data. For discrepancies in data, I used member checks to verify and explore the meaning and perspective of the participants' responses. The following chapter presents the results of this mixed methods data analysis.

CHAPTER 4

RESULTS

In this chapter, I present data collected from survey respondents and interview participants. The results and findings of the quantitative and qualitative data analyses are reviewed for each research question:

1. What are pre-service teachers' perceptions of educational neuromyths and general knowledge of the brain, learning, and behavior?
2. What is the self-reported likelihood of pre-service teachers to implement an array of instructional practices (effective and ineffective)?
3. Is there a relationship between perceptions of neuromyths and likelihood to implement corresponding instructional practices?
4. Is there a relationship between demographic factors and beliefs in educational neuromyths and general knowledge of the brain?
5. What are participants' perceived levels of preparedness in educationally relevant neuroscience literacy, what is their interest in learning about this topic, and what sources do they use for information about this topic?

As outlined in Chapter 3, I used a mixed method sequential explanatory design for this study. This method is characterized by the collection and analysis of quantitative data followed by the collection and analysis of qualitative data. The analysis of the qualitative data was used to help explain and expand upon the results of the quantitative analyses, creating a more comprehensive analysis of the research questions.

First, I describe analysis of the quantitative survey data for each of the four research questions. This analysis includes both descriptive and inferential statistics for responses to the survey instrument, including: (a) perceptions of educational neuromyths and general knowledge about the structure and function of the brain, (b) likelihood to implement an array of instructional practices, and (c) relations between demographic factors survey responses. I then present key findings and themes from the qualitative analysis of interview transcripts related to my research questions. Finally, I present convergences and inconsistencies between the quantitative and qualitative analyses.

Quantitative Data Analysis by Research Question

Research Question 1

The first research question of the study was: What are pre-service teachers' perceptions of educational neuromyths and general knowledge of the brain, learning, and behavior?

Quantitative data analysis for neuromyth prompts. Section two of the survey instrument assessed participants' perceptions of educational neuromyths and their general knowledge of the brain, learning, and behavior. This section was comprised of ten separate neuromyth statements (e.g., *individuals learn better when they receive information in their preferred learning style*) and 15 statements related to general knowledge of the brain (e.g., *vigorous exercise can improve mental function*). As described in Chapter 3, participants were given three possible response options to select from for each of these statements: (a) "correct," (b) "incorrect," and (c) "do not know." Table 3 shows the accuracy of participants' responses to the neuromyth statements.

Table 3

Responses to neuromyth statements

Neuromyth	Inaccurate	Accurate	Do not know
Individuals learn better when they receive information in their preferred learning style. (F)	77.0%	15.1%	7.9%
There are critical periods in childhood in which certain things can no longer be learned. (F)	71.1%	14.1%	14.8%
Short bouts of coordination exercises can improve integration of left and right hemispheric brain function. (F)	65.1%	4.0%	40.0%
Differences in hemispheric dominance (left brain, right brain) can help explain individual differences amongst learners. (F)	59.4%	18.0%	22.7%
Children must acquire their native language before a second language is learned. If they do not do so, neither language will be fully acquired. (F)	57.8%	23.4%	18.8%
Exercises that rehearse coordination of motor-perception skills can improve literacy skills. (F)	52.0%	7.8%	40.2%
Learning problems associated with developmental differences in brain function cannot be remediated by education. (F)	49.0%	16.7%	34.1%
Extended rehearsal of some mental processes can change the shape and structure of some parts of the brain. (T)	48.0%	10.2%	41.7%
It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement. (F)	28.3%	8.7%	63.0%
Individual learners show preferences for the mode in which they receive information (e.g., visual, auditory, or kinesthetic). (T)	4.7%	79.5%	15.8%

Note. T = True. F = False.

On average, individual participants responded inaccurately to 3.48 (34.8%) of the ten neuromyth statements (*SD* =1.79 or 17.9%). Individuals responded accurately to 3.56 (35.6%) of the ten statements (*SD* =1.79 or 17.9%). Individuals selected “do not know” for 2.88 (28.8%) of the statements (*SD* = 2.26 or 22.6%). Overall, individuals responded inaccurately or selected “do not know” for 63.6% of the neuromyth prompts.

The neuromyth prompts most frequently answered inaccurately were related to learning styles, hemispheric dominance, critical periods of development, and perceptual motor training. The item most frequently answered inaccurately was *Individuals learn better when they receive information in their preferred learning style* (77% of total responses). A total of 71.1 % of individuals inaccurately answered the following prompt: *There are critical periods in childhood in which certain things can no longer be learned.* This was followed by *Short bouts of coordination exercises can improve integration of left and right hemispheric brain function* (65.1% of total responses). In addition, 59.4% of individuals inaccurately responded to *Differences in hemispheric dominance (left brain, right brain) can help explain individual differences amongst learners.*

Overall, not many neuromyth statements were answered accurately. However, *Individual learners show preferences for the mode in which they receive information (e.g., visual, auditory, or kinesthetic)* received a relatively high percentage of accurate responses. This is a true statement, and 79.5% of participants marked it “correct.” The statement with the second highest number of accurate responses was *Children must acquire their native language before a second language is learned. If they do not do so, neither language will be fully acquired*. This is also a true statement, and 23.4% of participants answered it accurately.

Participants responded “do not know” to an average of 28.8% of the survey items. *It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement*, a false statement, received the most “do not know” responses (63%). The assertion with the second highest proportion of “do not know” responses was *Extended rehearsal of some mental processes can change the shape and structure of some parts of the brain*. This statement is true, yet 41.7% indicated uncertainty about this concept.

Quantitative data analysis for general brain knowledge prompts. In addition to the neuromyth prompts, the second section of the survey also included 15 statements related to general knowledge about brain function and structure. Table 4 shows the accuracy of participants’ responses to the statements related to general brain knowledge.

Table 4

Responses to general statements

General brain knowledge	Inaccurate	Accurate	Do not know
The left and right hemispheres of the brain always work together. (T)	38.3%	32.0%	29.7%
When a brain region is damaged other parts of the brain can take up its function. (T)	28.9%	42.2%	28.9%
We only use 10% of our brain. (F)	28.1%	43.0%	28.9%
Learning is due to the addition of new cells in the brain. (F)	17.2%	40.6%	42.2%
Normal development of the human brain involves the birth and death of brain cells. (T)	14.8%	48.4%	36.7%
Circadian rhythms ("body-clock") shift during adolescence, causing students to be tired during the first lessons of the school day. (T)	10.2%	59.8%	29.9%

Table 4 (continued)

General brain knowledge	Inaccurate	Accurate	Do not know
Brain development has finished by the time children reach secondary school (F)	9.4%	77.3%	13.3%
The brains of boys and girls develop at the same rate. (T)	7.8%	74.2%	18.0%
Mental capacity is hereditary and cannot be changed by the environment or experience. (F)	7.1%	75.4%	17.5%
Learning occurs through modification of the brains' neural connections. (T)	7.0%	57.0%	36.0%
Information is stored in the brain in a network of cells distributed throughout the brain. (T)	5.5%	69.5%	25.0%
Production of new connections in the brain can continue into old age. (T)	4.8%	73.0%	22.2%
Vigorous exercise can improve mental function. (T)	4.7%	75.6%	19.7%
There are sensitive periods in childhood when it is easier to learn things. (T)	3.9%	81.1%	15.0%
We use our brains 24 hours a day. (T)	1.6%	92.2%	6.3%

Note. T = True. F = False.

On average, participants responded inaccurately to 1.7 (11.5%; *SD* = 1.4 or 9.4%) and accurately to 9.4 (62.5%; *SD* = 2.7 or 18.9%) of the 15 statements. Participants responded “do not know” to 3.7 (24.5%; *SD* = 3.1 or 28.3%) of the 15 statements. Overall, individuals responded inaccurately or selected “do not know” for 36.0% of the prompts measuring their general knowledge about the brain.

The general knowledge prompts most frequently answered inaccurately were related to hemispheric dominance and brain plasticity. The true statement, *the left and right brain always work together*, was answered inaccurately by 38.3% of participants. Additionally, 28.9% of participants inaccurately responded to *When a brain region is* *damaged, other parts of the brain can take up its function.* The myth that humans only use 10% of their brain was answered inaccurately by 28.1% of respondents.

Many participants provided correct responses to several of the general knowledge prompts. For instance, 92.2% of participants accurately asserted that humans use their brains 24 hours a day, and 81.1% of participants accurately identified that there are sensitive periods during childhood when it is easier for children to learn things. In addition, 77.3% of participants indicated that brain development is not finished by the time students finish secondary school. A high percentage of respondents, 75.6%, accurately acknowledged the potential for vigorous exercise to improve overall mental function. In addition, 75.4% of participants indicated that mental function is not just hereditary and can be influenced by environment or experience, and 74.2% of respondents accurately asserted that brains of boys and girls develop at different rates.

Participants responded “do not know” most frequently to general knowledge statements related to neurogenesis (the growth and development of neurons), synaptogenesis (the formation of synapsis between neurons), and neural plasticity (the formation of new neural connections in response to environment and experience). For example, 42.2% of participants responded “do not know” to the false survey item, *Learning is due to the addition of new cells to the brain.* Thirty-six percent of participants responded “do not know” to the true statement, *Learning occurs through modifications of the brain’s neural network.* Additionally, participants were unsure about neurobiology concepts. This is evidenced by the frequency of “do not know” responses to the following items: (a) *Normal development of the human brain involves the birth and death of brain cells* (36.7% “do not know” responses), (b) *When a brain region is damaged other parts* *of the brain can take up its function* (28.9%), (c) *The left and right hemispheres of the brain always work together* (29.7%), and (d) *Information is stored in the brain in a network of cells distributed throughout the brain* (25.0%).

Summary. Overall, participants responded more accurately to general brain knowledge items compared to neuromyth statements. As shown in Table 5, participants were almost twice as likely to respond accurately to a general knowledge item than a neuromyth item. Neuromyth statements were over three times as likely to be answered inaccurately than general brain knowledge items. There was not a marked difference between the two question types and the number of "do not know" responses. Implications related to these results will be discussed in Chapter 5.

Table 5
Accuracy of response by statement type

Survey Item	Inaccurate	Accurate	Do not know
Neuromyth	34.8% (*SD*=17.9)	35.6% (*SD*=17.9)	28.8% (*SD*=22.6)
General brain knowledge	11.5% (*SD*=9.4)	62.5% (*SD*=18.9)	24.5% (*SD*=28.3)

Research Question 2

The second research question asked, What is the self-reported likelihood of pre-service teachers to implement an array of instructional practices?

Quantitative data analysis. As outlined in Chapter 3, the first section of the survey instrument listed 13 specific instructional practices. Based upon meta-analytic analyses, the list included practices identified as effective for children with disabilities (e.g., direct instruction) and practices identified as being ineffective or having no empirical support (e.g., modality training, teaching to different learning styles). Each instructional practice was followed by a short definition. Participants were asked to rate their likelihood of implementing each practice in the classroom using a 4-point Likert-type scale. Anchors for the four-point scale were "definitely will," "probably will," "probably will not," and "definitely will not." The practices were listed in random order in the survey, and participants were not given information about the level of effectiveness for each practice. Practices in Table 6 are rank ordered according to proportion of participants responding they "definitely will" implement the practice in their classroom.

Table 6

Likelihood of implementation of selected instructional practices

Instructional Practice	Definitely Will	Probably Will	Probably Will Not	Definitely Will Not
Formative Evaluation[a]	84%	16%	0%	0%
Direct Instruction[a]	82%	18%	0%	0%
Mnemonic Strategies[a]	60%	37%	3%	0%
Modality Training[b]	60%	38%	1%	1%
Applied Behavior Analysis[a]	57%	39%	4%	0%
Teaching to Multiple Intelligences[b]	44%	46%	9%	1%
Learning Style Inventories[b]	43%	47%	10%	0%
Perceptual Motor Training[b]	37%	55%	10%	1%
Neurological Repatterning[b]	44%	45%	14%	1%
Psycholinguistic Training[b]	33%	51%	13%	3%
Multiple Intelligences Questionnaires[b]	27%.	53%	17%	3%
Hemispheric Dominance Training[b]	17%	48%	32%	3%

Note. [a]Effective instructional practices, [b]Practices not demonstrated to be effective.

Four of the top six practices that participants selected for implementation are effective practices for students with exceptionalities: formative evaluation (84%), direct instruction (82%), mnemonic strategies (60%), and applied behavior analysis (57%). Two of the top six practices have not been demonstrated to be effective practices for students with exceptionalities: modality training (60%), and teaching to multiple intelligences (44%). Of note, modality training was ranked higher than applied behavior analysis.

When considering participants general support for instructional practice, I combined the two choices of *definitely will* and *probably will*; either response indicates an openness to implement a specific practice in the classroom. An examination of the data of these combined choices reveals most participants are willing to implement each of the ineffective instructional practices in the classroom. Table 7 shows the instructional practices rank ordered according to participants' indication that they *definitely will* or *probably will* implement the practice.

Table 7

Likelihood of implementation combined

Instructional Practice	Combined *definitely will* and *probably will*
Formative Evaluation[a]	100%
Direct Instruction[a]	100%
Modality Training[b]	98%
Mnemonic Strategies[a]	97%
Applied Behavior Analysis[a]	96%
Perceptual Motor Training[b]	92%
Teaching to Multiple Intelligences[b]	90%
Learning Style Inventories[b]	90%
Neurological Repatterning[b]	89%
Psycholinguistic Training[b]	84%
Multiple Intelligence Questionnaires[b]	80%
Hemispheric Dominance Training[b]	65%

Note. [a]Effective instructional practices, [b]Practices not demonstrated to be effective.

When accounting for both choices of *definitely* and *probably will*, participants indicated a likelihood of implementing ineffective instructional practices. As shown in the table, over 90% or greater of participants indicated a general willingness to implement modality training, perceptual motor training, and teaching to multiple intelligences, and using learning style inventories. Additionally, over 80% or greater of participants responded they are open to using psycholinguistic training, neurological repatterning, and multiple intelligence questionnaires.

Research Question 3

The purpose of the third research question was to examine relations between perceptions of neuromyths/general brain knowledge and likelihood to implement specific instructional practices. The goal was to investigate whether a relation exited between participants' neuroscientific knowledge and their selection of instructional practices (effective and ineffective) to implement in the their future classrooms. To do this, I calculated a practice differential, indicating the degree to which participants rated effective practices higher than ineffective practices. The practice differential was calculated as the mean rating for effective practices minus the mean rating for ineffective practices for each participant. I ran a correlation analysis between practice differential and percentage of accurate responses to neuromyth and general brain statements. Practice differential and accuracy of responses to neuromyths were positively and significantly related: $r(129)=.27$, $p=.002$. General brain knowledge and practice differential were positively but not significantly correlated: $r(129)=.091$, $p=.306$.

Additionally, I conducted Kruskal-Wallis tests to examine differences in likelihood to implement specific instructional practices as a function of responses to specific neuromyth items (accurate, inaccurate, and "do not know"). The "likelihood to implement specific instructional practices" was measured by the combination of *definitely* and *probably will* responses. I examined three neuromyth items and their corresponding instructional practices: learning styles, perceptual motor training, and hemispheric dominance.

In reference to learning styles, the Kruskal-Wallis test showed a statistically significant difference in likelihood to implement modality training across the three response types (accurate, inaccurate, and “do not know”): χ^2 (2) = 8.69, p = .013, with a mean rank score of likelihood to implement modality training of 47.39 for accurate responses to neuromyth item about learning styles, 69.07 for inaccurate responses to neuromyth item about learning styles, and 54.67 for “do not know” responses.

In reference to hemispheric dominance, a Kruskal-Wallis test showed a statistically significant difference in likelihood to implement hemispheric dominance training across the three response types (accurate, inaccurate, and “do not know”): χ^2 (2) = 17.43, p < .001, with a mean rank score of likelihood to implement hemispheric dominance training of 37.63 for accurate responses to neuromyth item about hemispheric dominance, 71.28 for inaccurate responses to neuromyth item about hemispheric dominance, and 68.05 for “do not know” responses.

There was no statistically significant difference in likelihood to implement perceptual motor training across the three response types (accurate, inaccurate, and “do not know”): χ^2 (2) = 2.89, p < .236, with a mean rank score of likelihood to implement perceptual motor training of 47.65 for accurate responses to neuromyth item about perceptual motor training, 67.04 for inaccurate responses to neuromyth item about perceptual motor training, and 64.52 for “do not know” responses.

Research Question 4

The fourth research question of the study was, Are there correlations between demographic factors and beliefs in neuromyths and general knowledge of the brain? This question sought to explore relationships between specific demographic factors and responses to neuromyth statements and general statements about the brain. I examined survey responses in relation to three specific demographic factors: (a) self-reported level of preparedness (i.e., educational neuroscience literacy), (b) number of completed education courses, and (c) number of completed science courses (biology, anatomy, physiology, psychology, etc.).

Perceived level of preparedness. To gather data about perceived levels of preparedness in educational neuroscience literacy, participants were asked to respond to the following prompt: *Courses you have taken in the College of Education have provided you with information about the structure and function of the brain as it relates to learning.* Participants could one of the following: “strongly agree, “somewhat agree,” “neutral,” “somewhat disagree,” and “strongly disagree.” Survey data indicated that 13.6% of participants “strongly agree,” 44.0% of participants “somewhat agree,” 23.2% of participants were “neutral” on this topic, 16.8% of participants “somewhat disagreed,” and 2.4% of participants “strongly disagreed.”

I ran a correlation analysis to examine the strength of the relation between perceived level of preparedness and accuracy of responses to survey items related to *both* neuromyth statements and general brain knowledge prompts. There was a significant and negative correlation between “I don’t know” responses and perceived level of preparedness: $r(129) = -.19$ $p=.030$. There was not a significant relationship between (a) accurate survey responses and perceived level of preparedness, $r(129) = .14$, $p=.116$, nor between inaccurate survey responses and perceived level of preparedness, $r(129) = .17$, $p=.063$. I also examined the strength of the relation between *number of education courses* and *perceived level of preparedness*. There was a moderate, positive, and statistically significant correlation between the number of education courses completed and reported level of preparedness: $r(129) = .21$, $p=.028$.

Number of education courses. Participants were also asked to indicate the number of education courses they had completed at the time of the survey. Participants indicated they had completed a mean of 8.4 education courses (*SD*= 4.1). A moderate, positive, statistically significant correlation was demonstrated between number of education courses and accurate survey responses: $r(129) = .24$, $p=.013$. There was also a moderate, negative, statistically significant correlation between number of education courses and "do not know" responses: $r(129) = -.25$, $p=.010$. There was not a statistically significant relation between number of education courses and inaccurate responses: $r(129) = .13$, $p=.182$.

Number of science courses. Participants were asked to indicate the number of science courses they had completed at the time of the survey. Survey responses indicated participants had completed a mean of 1.6 science courses (*SD*=2.6) There was a moderate, positive, statistically significant correlation between number of science courses and accurate survey responses: $r(129) = .34$, $p<.001$. Additionally, a moderate, negative, statistically significant correlation was demonstrated between number of science classes and "do not know" responses: $r(129) = -.22$, $p=.014$. There was not a statistically significant relation between number of science courses and inaccurate responses: *r*(129) = -.08, *p*=.357.

Relation of demographics to neuromyth responses. I also conducted correlation analyses for demographic factors and responses to just neuromyth items. In these analyses, I excluded responses to general brain knowledge prompts. Similar to the above section, I analyzed the data according to perceived level of preparedness, number of education courses, and number of science courses.

Perceived level of preparedness. Specific to neuromyths, there was a moderate positive correlation between perceived level of preparedness and inaccurate responses to neuromyths statements: *r*(129) = .22, *p*=.014. There was also a moderate, negative, statistically significant relationship between perceived preparedness and "do not know" responses: *r*(129) = -.22, *p*=.013. There was not a statistically significant relation between perceived level of preparedness and accurate responses: *r*(129) = .07, *p*=.457.

Number of education courses. Specific to neuromyths, there was a moderate, positive, significant correlation between number of education courses and accurate responses: *r*(129) = .21, *p*=.020. There was not a statistically significant correlation between number of education courses and inaccurate neuromyth responses: *r*(129) = -.06, *p*=.483. Additionally, there was not a statistically significant correlation between number of education courses and "do not know" responses: *r*(129) = -.11, *p*=.206.

Number of science courses. Specific to neuromyths, there was a moderate, positive correlation between number of science courses and inaccurate responses: *r*(129) =.22, *p*=.014. There was also a moderate negative correlation between number of science courses and "do not know" responses: *r*(129) = -.22, *p*=.013. There was not a statistically significant relationship between number of science courses and accurate responses to neuromyth prompts: $r(129) = .07$, $p = .457$.

Research Question 5

The fifth research question for the study asked, What is participants' perceived level of preparedness in educationally relevant neuroscience literacy, what is their interest in learning about this topic, and what sources do they use for information about this topic?

At the end of the survey, participants were prompted to provide additional information about their attitudes related to learning about the brain and its influence on learning and behavior. They were asked to respond to the following prompt: *How interested are you in scientific knowledge about the brain and its relation to learning, behavior, and instructional practices?* Participants rated their interest level on a five-point Likert type scale. Survey data indicate that 31.8% of participants are "strongly interested," 46.8% are "somewhat interested," 17.5% marked "neutral," 2.4% are "somewhat disinterested," and 1.6% are "strongly disinterested."

In addition, I gathered information about the sources participants used for information about the brain, learning, and behavior. Participants were given several options to choose from following the prompt: *What is your main source for information about learning, behavior, and the brain? Mark all that apply*. Survey data indicate that 83.9% of participants selected "University courses," 42.7% selected "Scholarly journals," 40.3% selected "Popular press and media," and 9.7% selected "Online or other sources."

If participants selected "online or other sources," they were directed to list the specific source. Responses given for online sources used by participants (n=12) included the websites Common Sense, PBS, National Geographic, the Science Channel, Ted-Ed, and Crash Course. Two participants indicated they used Google and general online articles. Information given for "other" sources varied widely. Responses included leisure reading, the workplace, the television show *Grey's Anatomy*, and individuals outside of education the participants perceived as knowledgeable about this topic (i.e., family members and former teachers).

Qualitative Data Analysis by Research Question and Themes

Adhering to the sequential explanatory mixed methods design, after analysis of the quantitative survey data I conducted individual interviews (*n*=6) to gather qualitative data to improve the quality of the study findings. I used the quantitative data to inform the development of the semi-structured interview prompts. Interview questions were related to the research questions and prompted participants to provide a rationale and context for their survey responses.

Prior to each interview, I analyzed each participant's quantitative responses to the survey instrument; knowledge of individual survey responses enabled me to tailor my interview questions for each participant within the pre-determined interview topics. The analysis of my qualitative findings is presented according to the prompts of my semi-structured interview guide. Questions were structured around three general topics: (a) justification for reported likelihood to implement instructional practices informed by common neuromyths, (b) perceived level of preparedness to discriminate between effective and spurious instructional practices, and (c) interest in learning more about the structure and function of the brain as it relates to learning and behavior.

Likelihood to Implement Specific Instructional Practices

During each interview, I questioned participants about their responses to the first section of the survey (likelihood to implement an array of specific effective and ineffective practices). I predominantly focused this section of the interview on three common neuromyth-driven instructional practices: modality training (i.e., teaching to particular learning styles), perceptual motor training (e.g., Brain Gym®), and hemispheric dominance (i.e., instruction for “right brain” vs. “left brain” learners). I chose to focus on these practices because many study participants indicated a likelihood to implement these practices in the classroom. The following section presents interview participants’ explanations and justifications for the use of these practices.

Modality training. The survey asked respondents to indicate their likelihood (“definitely will,” “probably will,” “probably will not,” or “definitely will not”) to implement modality training. The survey prompt was worded as follows: *Modality training – Providing instruction for children based upon their preferred modality*. Five of the six participants indicated in their survey they “would definitely” incorporate learning styles in their classroom instruction.

One participant indicated she would “definitely not” plan her instruction according to specific learning styles. She gave a lengthy and articulate justification in the interview. She stated that in her program, she was taught that “learning styles is a myth.” She then went on to say:

> My program really stressed the importance of using evidence-based practices, and I think, at least two of my professors told us that the use of learning styles in the classroom is not evidence-based. In some of my courses, sometimes, other students mentioned learning styles and it was talked about a little bit, but my professors didn’t tell us that this is something we should be focusing on in the

classroom.

The same student also talked about the importance of using research to verify the effectiveness of instructional practices, and said she frequently checks What Works Clearinghouse.

Although this participant definitively spoke out against the validity of teaching to specific learning styles, she did acknowledge the need to provide students with multiple means of representation and engagement. For instance, she shared that her mentor teacher often had students clap along when reciting spelling words and practice air-writing vocabulary words. She stated she planned on using these strategies in her own classroom. She expressed that although she was skeptical about teaching to specific learning styles, she believes that "students need to be provided with a variety of audio and visual supports." She then went on to talk about the importance of Universal Design for Learning (UDL) and the need to provide students with multiple means of engagement and expression. She stated, "this should be provided for all students, not just ones that you think are a specific type of learner."

When questioned about learning styles, the other five students emphatically expressed the need to identify the individual "types" of learners in their classrooms. Several participants said they planned on using learning style inventories to determine how each of their students learns best. However, one of the participants expressed confusion about the use of learning style inventories. She stated that her mentor teacher administered learning style inventories to her students, but then "never really seemed to do anything with the information on the surveys."

These five students all shared the belief that teaching to individual learning styles was an evidence-based instructional approach. Several noted they were taught about learning styles in their education courses, and that either they or their classmates had given presentations in their teacher preparation courses about the importance of teaching to specific learning styles. Interestingly, one of the participants stated that in the state of Illinois, special education teachers are required to indicate the specific learning style (visual, auditory, or kinesthetic) of a student in their IEP. She followed this information by saying, "I would just check all of the boxes because you don't really know what will work best."

I prompted each of these participants to provide examples of how they might teach to individual learning styles and was given several examples. For visual learners, three participants mentioned using videos to present content. Two participants talked about the importance of using anchor charts and posting schedules for visual supports. One of the participants spoke about using large vocabulary cards with pictures that accompany the Wonders curriculum. For auditory learners, three of the participants talked about the importance of using audio books and computer programs that provide narrations of electronic books. One of the participants mentioned a strategy she named, "Call the Dog." She said her mentor teacher used this strategy for vocabulary words or words difficult to pronounce. The strategy requires students to say the vocabulary word in a singsong fashion, similar to how you might call out the name of the dog. She claimed this type of articulation aids in pronunciation and retention of new vocabulary words.

When I inquired as to how the participants supported kinesthetic learners, I received few specific examples. Several participants stated the importance of using manipulatives for math concepts. One of the participants stated she thought it was important for kinesthetic learners to have fidget toys; she spoke specifically about fidget "cubes," which are currently growing in popularity. "Four Corners" was another kinesthetic approach mentioned. In this technique, the teacher poses a statement or question. In each corner of the classroom, a sign is posted (e.g., "agree," "disagree") and students move to the corner that is aligned with their opinion. In general, interview participants were not able to provide many specific kinesthetic strategies.

Similar to the participant who did not support the use of learning styles, several participants mentioned UDL when speaking about their support for auditory, visual, and kinesthetic considerations within instruction. Several of the participants appeared to use the phrases "learning styles" and "UDL" interchangeably. In addition, several participants spoke about differentiation. During their descriptions of differentiation, they seemed to conflate the principles of UDL and teaching to specific learning styles.

Additionally, none of the participants spoke about using learning styles to support *individual* students. Participants spoke enthusiastically about their beliefs that students have unique learning styles. Yet when prompted, they stated they would incorporate visual, auditory, and kinesthetic supports for all students, not individual students. One participant stated:

> I think all students have different learning styles, but it is not possible to teach to each child's learning style in a classroom of 20 students. Maybe, I might know that one student really needs to move, but that's about it. Instead, I think teachers should just be mindful to run their classroom in a way that always considers visual, auditory, and kinesthetic learners.

Another participant described it this way:

> Maybe one student is a visual learner. I think, though, it is good to focus on all learning styles. Everyone has a dominant way that we learn the best. They should be exposed to all different means, to strengthen areas that might be a little weaker, so that we are hitting all learners.

The participants seemed to suggest that, although they believed in individual learning styles, they planned to use a variety of visual, auditory, and kinesthetic techniques for all the students in their classrooms. Instead of targeting the unique learning styles of individual students, participants indicated their implementation of learning style constructs should be a whole group instructional approach.

Perceptual motor training. I asked respondents to indicate their likelihood to implement perceptual motor training on the survey. The survey prompt was worded as follows: *Perceptual Motor Training – Programs designed to improve academic skills by enhancing sensory and motor skills (e.g., Brain Gym®).* According to survey data, four participants indicated they "probably will" implement perceptual motor training, and two of the participants indicated they "definitely will" implement perceptual motor training.

Although all six participants indicated they plan to implement a form of perceptual motor training, their understanding of the concept varied. The two participants that indicated they "definitely will" utilize perceptual motor training in the classroom had witnessed mentor teachers either using the Brain Gym® curriculum or, at a minimum, refer to the Brain Gym® curriculum. One of the participants said her mentor teacher had a spiral bound notebook of the Brain Gym® movements and occasionally used it at various points throughout the day. I asked this participant to explain the Brain Gym® curriculum to me, and she stated:

> Basically, it is a set of movements that help to coordinate physical movement and mental activity. For instance, um, Brain Gym® has like a menu of different academic areas you might want to focus on. If a student has problems with reading comprehension, then the student would do a particular movement to help improve their reading comprehension.

After this explanation, I prompted the student to provide a rationale for aligning specific physical movements with discrete cognitive deficits. She stated that she “didn’t know how it works, but it comes in a research-based curriculum.” When I questioned her about the research base of Brain Gym®, she expressed surprise. She stated that her mentor teacher was “an excellent teacher who emphasized using research-based interventions.”

The justification of the other participant who stated she “definitely will” implement perceptual motor training was markedly different. She stated that she had heard about the curriculum and that she had seen some of the curriculum present in various classrooms. She was not exactly sure how it worked, or even the specific aim of the program. However, she selected she “definitely will” implement it because she saw it in other classrooms.

Four of the participants that selected they “probably will” implement perceptual motor training did not appear to understand the definition provided in the survey prompt. I inquired as to whether they were familiar with the program Brain Gym®**.** None of them were familiar with the specific program. I subsequently explained the definition provided in the survey about perceptual motor training. I stressed that perceptual motor training involves the use of physical movement to improve specific academic skills. I explained to the participants that the Brain Gym® curriculum claims to target specific areas, including reading, writing, and listening skills. During my individual interviews with these four participants, none of them supported the idea that choreographed movements could ameliorate deficits in specific content areas. Instead, they chose to talk about the general benefits of incorporating student movement in the classroom.

The majority of these participants steered the discussion away from perceptual motor training to the increasingly popular classroom practice known as "brain breaks." This is a generic term that refers to interspersing acute exercise throughout the day. The participants shared they felt it was necessary to incorporate physical movement breaks throughout the day, and provided a variety of examples, including intermittent stretching breaks, yoga, jumping jacks, running in place, and teacher or student led games of "Simon Says." Two of the six participants stated they regularly used or observed "Go Noodle," a computer-based movement program designed to help with focus, mindfulness, and transitions (https://www.gonoodle.com). Participants stated they either would incorporate "brain breaks" at regularly scheduled intervals throughout the day, or when they observed the students to be "inattentive," "sluggish," or "bored."

Only one of the participants spoke out against the regular use of "brain breaks." She stated that in a well-run classroom there is no need for "brain breaks." She believed that "classrooms with meaningful stations and a variety of activities at each station incorporate enough amount of movement and engagement." She also stated that in special education classrooms, sometimes a "brain break" creates problems and escalates behaviors. According to her, "if a roomful of students are working productively, or even experiencing minor disruptions, brain breaks can create total chaos." It was clear that participants felt strongly about the importance and effectiveness of "brain breaks."

However, the survey question was not about "brain breaks," it was about perceptual motor training. It appears participants confused these two concepts.

Hemispheric dominance training. I asked respondents to indicate their likelihood to implement hemispheric dominance training on the survey. The survey prompt was worded as follows: *Hemispheric Dominance Training – Tailoring instruction to address the different learning needs of "left brain" and "right brain" learners.* Compared to modality training and perceptual motor training, mean responses indicated participants were less likely to implement this practice.

Half of the six participants indicated in the survey they "probably will" implement hemispheric dominance training; the other half indicated they "probably will not" implement hemispheric dominance training. During my discussions with the participants who indicated they probably would incorporate hemispheric dominance training in the classroom, they were not able to provide concrete, specific examples of what this training might look like. When prompted, the individuals did not outline specific strategies, instead they spoke about the influence of hemispheric dominance on personality traits. For instance, one of the participants stated, "I know that left-brained individuals tend to be logical, and right-brained individuals tend to be more creative. This means I want to provide both logical and creative outlets for my students." This sentiment was repeated by two other participants. They both expressed the common adage that left-brain individuals are logical and right-brain individuals are creative. They conveyed they would like to provide outlets for these two types of "thinking styles." They spoke generally about the importance of infusing art and science, but did not provide specific strategies for targeting "left-brain" or "right-brain" learners in the classroom.

Two other participants stated they had heard of the phenomenon of left-brain vs. right-brain learners. However, they were skeptical about practical applications in the classroom. As one participant stated,

> I believe in the idea of left-brain vs. right-brain learners. I am a left-brain learner, I am very logical and detail oriented. My husband is a right-brain learner. I think that is one of the reasons we make a good match. I think my students may be right-brain or left-brain learners, but that doesn't mean I make their work different. I think I just try to incorporate creative and mathematical concepts into everything we do.

The sixth interview participant stated she didn't really believe in the "hype" around hemispheric dominance and didn't think about it when she planned her classroom instruction.

Perceived Level of Preparedness in Education Neuroscience

As part of each interview, I questioned the participants about their perceived level of preparedness related to educational neuroscience. I specifically asked them if they felt their education courses provided them with exposure to basic neuroscientific principles relevant for teaching students with exceptionalities. I also inquired as to whether they were provided with a neurophysiological understanding of the etiology of a variety of exceptionalities. Across the board, participants stated they were not provided with this type of information in their teacher education programs.

However, in response to this line of questioning, several of the participants reiterated that their education programs did provide them with a strong foundation in UDL and the importance of evidence-based practices. Their responses were consistent with answers given to other interview questions. When asked about any number of topics (e.g., learning styles or neuroscience research) participants consistently returned to their instruction related to learning styles, differentiation, UDL, and evidence-based practices. They tended to speak about these practices, approaches, and ideas ambiguously and interchangeably. It was apparent they had been taught about many evidence-based instructional practices, but tended to use vague terminology when discussing discrete practices.

Interest in Educational Neuroscience

At the conclusion of each interview, I asked each participant if they were interested in learning more about educational neuroscience. Across all participants, answers were positive, although individuals expressed a variety of reasons and motivations. Several of the participants stated they wanted to learn more about the neurophysiology of exceptionalities because they just wanted to know as much about their students as possible. Educational neuroscience was viewed as a novel data source to determine how to best service their students. One of the participants expressed a desire to learn more about educationally relevant neuroscience because she felt it would improve her practice, but also because it could just add more "professional respect" to the teaching profession.

Overwhelmingly, however, the interview participants stated they only wanted to learn about neuroscience if it could directly inform their classroom practice. As one participant stated,

> I have a million decisions I might need to make. I need to know what to do. I don't have the luxury to figure out a neuroscience study. Somebody else should

> figure that out, tell me what that means, and then I will do it.

This sentiment aligned with another participant's perspectives. She expressed that she found neuroscience interesting, but then stressed that first and foremost, "she was a teacher." She followed this with the opinion that other professionals, probably at the university level, should do the translation for her. She concluded that she "trained to be a teacher, not a neuroscientist, but if neuroscience can help me, then I am open to suggestions."

Summary

In this chapter I presented general quantitative and qualitative findings of the research study. In the next chapter, I will expand upon the meaning of these findings. I will provide interpretations and explanations, as well as study limitations. I will also provide recommendations for future research and practice related to neuromyths and special education teacher training.

CHAPTER 5

DISCUSSION

The purpose of this study was to examine pre-service special education teachers' perceptions of neuromyths; their general knowledge about the brain, learning, and behavior; and their self-reported likelihood to implement an array of instructional practices (ranging from ineffective to highly effective). I also sought to examine relations between participants' perceptions and knowledge, demographic variables, and their likelihood to implement effective versus ineffective practices. Additionally, I gathered information about participants' interest level in neuroscience, whether they felt their education coursework provided them with a foundation in educational neuroscience literacy, and sources of information related to neuroscience and education. After analyzing the quantitative survey data, I conducted follow-up individual interviews with six participants. I designed these semi-structured interviews to gather additional information from the participants related to the research questions. In the following sections, I provide an interpretation of the quantitative and qualitative findings within the context of related literature, discuss potential implications of study findings for educational research and practice, offer recommendations for future research, and describe the limitations of this study.

Interpretation and Explanation

In this section I interpret primary findings and offer possible explanations for the results of both quantitative and qualitative data analysis. This discussion is contextualized within extant research related to my research topic. When appropriate, qualitative findings will be used to help interpret and explain quantitative findings.

Pre-service Teachers' Perceptions of Educational Neuromyths and General Knowledge of the Brain, Learning, and Behavior

As presented in Chapter Four, participants' responses to the survey instrument generally indicate misperceptions of neuromyths and moderate gaps in general knowledge of the brain, learning, and behavior. Mean correct responses to neuromyth prompts were 35.7% (*SD*=17.9), and mean correct responses to questions about general brain knowledge were 62.5% (*SD*=18.9). These data are generally consistent with findings from studies on neuromyths in other countries (e.g., (Dekker et al., 2012; Deligiannidi & Howard-Jones, 2015; Gleichgerrcht et al., 2015; Karakus et al., 2015).

There are seven extant studies on neuromyths that, similar to this study, sought to measure teachers' perceptions of neuromyths. Several of these studies also assessed teachers' general knowledge of the brain related to learning and behavior. Divergent methods and instruments of some of the studies preclude a direct comparison of results in the categories of neuromyths and general brain knowledge. However, meaningful comparisons between study results and research studies conducted in Turkey (Karakus et al., 2015), Latin America (Gleichgerrcht et al., 2015), and the United Kingdom and the Netherlands (Dekker et al., 2012) can be made due to survey similarities. Each of the aforementioned studies included survey sections comprised of the 12 neuromyths identified by OECD in 2002, and 20 identical questions about general brain knowledge. The sections of the survey used in this present study related to neuromyths and general brain knowledge replicated the survey instrument used in Turkey, Latin America, the United Kingdom, and the Netherlands. See Table 8 for a comparison of results across countries.

Table 8

Percentage of correct responses across studies

Country/Region	Participants	Neuromyths	Brain Knowledge
Latin America	N=3,451	38.0% (*SD*=13.8)	66.7% (*SD*=13.5)
Netherlands	N=105	49.0% (*SD* not reported)	73.0% (*SD*=12.7)
Turkey	N=278	53.0% (*SD*=27.8)	56.9% (*SD*=25.7)
United Kingdom	N=105	49.0% (*SD* not reported)	67.0% (*SD*=13.5)
United States	N=131	35.7% (*SD*=17.9)	62.5% (*SD*=18.9)

Participants in the current study from the United States answered fewer neuromyth statements correctly, but given the relatively large variability in responses across participants in some studies (and unreported variability in others), it is difficult to draw definitive conclusions about the lower mean of United States responses. However, these data do indicate an interesting pattern; across all studies, participants from all countries performed better on their responses to questions about general brain knowledge than neuromyth statements.

Although all seven of the extant research studies did not use the Dekker et al. (2012) survey for neuromyths and general brain knowledge, all of the studies did examine participants' perceptions of neuromyths related to instructional practices. The wording of the surveys varied slightly across studies, but the general purpose of all of the studies was to explore participants' perceptions of educational neuromyths. Of note, three commonly accepted neuromyths (modality training [i.e., learning styles], perceptual motor training, and hemispheric dominance) consistently ranked in the top three for most frequent “incorrect” responses to neuromyth statements in all of the research studies, including the present study.

It is encouraging to note that participants of the current study, on average, answered more survey prompts correctly than participants from all other studies for each of the three common neuromyths. Compared to participants in other studies, all participants in this study were initial-licensure special education teacher candidates. The participants in the other studies were in-place K-12 general education teachers, and the Latin American study also included education professors. Similar to this study, a portion of the Switzerland participants were pre-service teachers. Perhaps participants in this study performed better on these items because they were all pre-service teachers and were currently taking university classes. It is also possible that their special education coursework provided a stronger foundation in educational neuroscience literacy than their general education counterparts. The purpose of this study was not to compare the performance of in-place teachers versus pre-service teachers, or special education teachers versus general education teachers. However, these data suggest an area of interest for further research. Overall, it is noteworthy that such a large percentage of participants across countries believe so strongly in these three educational neuromyths.

Why do neuromyths exist and persist? For decades, education scholars have bemoaned the pervasiveness of neuromyths within educational practice (see Alferink & Farmer-Dougan, 2010; Howard-Jones, 2008; Pasquinelli, 2012). However, these editorial pieces lacked empirical evidence to demonstrate that teachers actually believed in neuromyths. It was only recently that researchers began to investigate in-service and pre-service teachers’ perceptions of neuromyths. Research findings are important because they contribute to the empirical evidence about pre-service teachers' beliefs related to neuromyths and instructional practices. Significantly, in concert with the results of similar studies, the present study suggests that educational neuromyths are very popular among teachers and are still thriving in the educational community. The findings of this study, bolstered by results from prior research, warrant an examination of the continued persistence of neuromyths among educators.

One of the reasons why neuromyths are so resilient is that they are partially based upon empirical findings. For instance, it is true that individual students may have a learning style preference (OECD, 2002). However, to date, there is no known evidence to support the theory that teaching students in their preferred learning style improves academic achievement. Additionally, brain lateralization and specialization is commonly accepted within the neuroscience community (Francks, 2015; Springer & Deutsch, 1998). However, there is no empirical evidence to support the idea that instruction designed specifically for right-brain or left-brain learners will improve academic or behavioral outcomes. Moreover, many research studies have demonstrated improved academic and behavioral outcomes for students with exceptionalities when they engage in antecedent bouts of physical exercise (Tomporowski, Davis, Miller, & Naglieri, 2008; Verburgh, Königs, Scherder, & Oosterlaan, 2014). However, this research does not, in any way, support the use of perceptual motor training (e.g., programs like Brain Gym®). The Brain Gym® curriculum asserts that *specific* movements (e.g., unrolling the ear cartilage from top to bottom several times) correlate with explicit academic or behavioral outcomes (e.g., improved reading comprehension). These three examples highlight the confusion that is caused when practices are partially based upon empirical evidence.

The "Decade of the Brain," an interagency initiative sponsored by the Library of Congress and the National Institute of Mental Health, helped create an appetite among the general public for news and media related to neuroscience. Coined "neurophilia," this public affinity for neuroscience stories, especially when accompanied by neuroimages, resulted in widespread neuroscience coverage in newspapers and popular media (Abi-Rached, 2008; Racine, Bar Ilan, & Illes, 2006). This development continues to contribute to the dissemination of neuromyths as articles published in the popular press tend to be sensationalistic and lacking in detail. Oftentimes, these reports contain erroneous scientific findings or the misinterpretation of experimental results (Pasquinelli, 2013).

Findings from this study and prior neuromyth studies suggest this trend has affected educators' beliefs. On the survey instrument, participants were asked to respond to the following prompt: *What are your sources for information about learning, behavior, and the brain?* They were allowed to select more than one of several sources ("popular press and media," "scholarly journals," "university courses," or "online or other sources"). It is concerning that 40.3% of participants selected, "popular press." Additionally, another 9.7% selected "online or other sources." Of those who selected "online sources," few participants provided reliable online sources for locating evidence-based practices in education. Moreover, some individuals reported turning to questionable sources for information about the brain, including friends, family members, and TV shows (i.e., *Grey's Anatomy*).

Other studies produced similar findings. For example, during interviews, Turkish participants were asked: "*How do you improve yourself with regards to your profession*?" The majority of the participants stated they improved their practice by searching the internet (sites unspecified) or sharing stories with their colleagues; most participants appeared to turn to informal sources for information about effective instructional practices (Karakus, Howard-Jones, & Jay, 2015). Likewise, findings of the Portuguese study revealed that teachers received most of their information about learning and the brain from the television and generic Internet sites, with few participants accessing peer-reviewed journals (Rato et al., 2013).

According to study findings, the majority of United States initial licensure candidates reported their main source for learning, behavior, and the brain was their university courses (83.9%). This is encouraging, as education professors and instructors can and should be reliable sources for evidence. However, education professors and instructors are also exposed to educational pseudoscience peddled in the popular press and media, and are not immune to the mechanisms that promulgate and maintain educational neuromyths. During the interviews, several participants stated they had learned about learning styles in their education courses. They stated they either learned about this practice from their professors or from presentations by their colleagues.

Similarly, in the Swedish study, 29% of the teachers surveyed reported they were exposed to learning styles as an effective instructional approach during their teacher education courses (Tardif et al., 2015). In the current study, only 13.6% of participants expressed that their teacher education courses prepared them to be critical consumers of educationally relevant neuroscience information, and five out of six of the interview participants stated they did not feel their college of education courses adequately prepared them in this area. These data could partially explain why participants performed worse on prompts related to neuromyths than general brain knowledge. During their training, teachers may be repeatedly exposed to educational neuromyths; this frequent exposure may create an illusion of instructional legitimacy.

Relatedly, in the study of Latin American teachers, the authors found that professors in higher education did not provide more correct responses to neuromyth statements than other educators (Gleichgerrcht et al., 2015). These findings raise questions about contemporary teacher education curricula, and suggest that education professors may also need to be provided with educational neuroscience training.

This is not to suggest that education professors are poorly trained, or not aware of the importance of teaching their students about evidence-based practices. Instead, the inability of education professors to identify neuromyths, and the general confusion surrounding neuroscience and education may be partially caused by inadequate translational research. For some time now, scholars have written about the potential of neuroscience to improve the identification and instruction of students with exceptionalities. It has been nearly 40 years since education psychologists Fuller and Glendening (1985) coined the term "neuroeducator." Neuroeducators would work at the intersection of neuroscience and education, translating relevant neuroscientific findings to help bridge the apparent gap between research and practice in special education.

However, the field of neuroscience and special education are still in the early stages of collaboration. Quite simply, it is difficult to directly translate neuroscience research findings to educational practice. This is not surprising, given the oft-cited challenges of bridging the research-to-practice gap related to instructional practice (Cook, Cook, & Landrum, 2013). Given the documented difficulties of translating educational research to practice and the relative lack of understanding of neuroscience among educators, bridging the neuroscience research to education practice seems like a lofty ambition.

There are many specific barriers involved in translating neuroscience research for special education practice. Professionals in these disparate fields employ different research methods, use language that is idiosyncratic to their work, and function in academic silos divided by the character of “soft” versus “hard” science. As Ansari and Coch (2013) suggested, the fields of neuroscience and education are connected by “bridges over troubled waters” (p. 146). All of these challenges are further amplified by the lack of clear leadership for the emerging discipline of neuroeducation. Currently, neuroeducation research is being conducted and disseminated in a wide range of venues, including various graduate programs, university think-tanks, for-profit workshops, professional development talks, and state-wide initiatives.

One of the research participants shared that in the state of Illinois, teachers are required to select the specific learning style of students in their IEPs. She stated she presumed learning styles were evidence based since the state mandated by law they be included in students’ IEPs. In-service and pre-service teachers are continually being given mixed-messages about neuromyths, and it is challenging for them to discern who and what to believe. This confusion about terminology and neuromyths became clear during the follow-up interviews. Many interview participants indicated on the survey they believed in specific neuromyth practices (e.g., learning styles), however during interview discussions, it became clear that several participants did not have the same understanding of learning styles as researchers. This misinterpretation of neuromyth vocabulary could be one possible reason for high rates of "incorrect" responses to neuromyth statements in the survey.

The practical difficulties of translational research pose meaningful challenges for both teacher educators and their students. University instructors are ill equipped to provide useful tips from neuroscience research for their teacher candidates. Moreover, both professors and candidates are frequently unable to discriminate between sound instructional practices based on neuroscience and practices mired in pseudoscience. Teachers do not have the luxury of simply applying novel neuroscience findings directly to their classroom instruction (Ansari & Coch, 2006).

Challenges surrounding the serpentine translation of neuroscience findings to classroom practice emerged during the quantitative and qualitative inquiries about participants' interests in learning about educationally relevant neuroscience. One of the survey prompts asked participants to indicate their level of interest in this area; over 70% of participants stated they were either "somewhat" or "strongly" interested in learning more about this topic. These data are similar to findings in other studies on neuromyths; more than half of the extant research studies on neuromyths discuss the extensive interest among teachers in the application of neuroscience to educational practice (Dekker et al., 2012; Gleichgerrcht et al., 2015; Karakus et al., 2015; Tardif et al., 2015). In the qualitative interviews, I queried participants about the source of their interest. I wanted to explore the reasons why participants were so interested in learning more about neuroscience and educational practice. Notably, all of the participants stated they only wanted to learn more about this topic if it could provide them with effective, specific instructional approaches to use in the classroom. None of the participants expressed they had a general curiosity about neuroscience, or that they wanted to expand their understanding of the neurophysiology of the brain. Instead, all the participants stated their interest was contingent upon research yielding practical suggestions for classroom practice. These qualitative findings highlight the practical urgency for researchers in both neuroscience and special education to increase their collaborative efforts to articulate findings specifically appropriate for everyday classroom teachers.

Likelihood of Pre-service Teachers to Implement Effective and Ineffective Instructional Practices

Unlike the other extant studies on neuromyths, this survey included a section that specifically prompted participants to rate their likelihood of implementing an array of instructional practices (both effective and ineffective). As outlined in Chapter Four, participants indicated a willingness to implement many practices founded upon neuromyths. Quite troubling, participants indicated a higher likelihood to plan their instruction according to learning modalities than implement Applied Behavior Analysis.

During follow-up interviews, I asked participants to explain their rationale for implementing questionable instructional practices. I was surprised to discover that some of the participants indicated they would implement practices that they didn't fully understand. For instance, several of the participants indicated they would implement perceptual motor training; however, in our discussions, it became apparent they did not fully understand the details of perceptual motor training (although a definition was provided in the survey). The Swedish study also revealed a similar finding (Tardif et al., 2015). When participants were asked about Brain Gym**®,** only one (of six) reported they "knew" about it, but five of the same participants indicated it should be implemented in the classroom. This seems counterintuitive. Why would individuals be willing to implement an instructional practice if they do not know what the practice is?

One possible explanation is the enticing appeal of neuroscience. It has been demonstrated that scientific jargon can add unwarranted credibility and legitimacy to a range of constructs. People tend to add meaning to ideas or statements if they are accompanied by "hard" science information (Weisberg, Keil, Goodstein, Rawson, & Gray, 2009). Thus, a practice with a name or description that is associated with neurology or other biological evidence may cause some teachers to consider implementing a specious "scientifically-based" instructional practice even though they do not know much about the practice itself.

The data for participants' likelihood to implement specific instructional practices also reveal that most participants were willing to consider implementing just about any practice in the classroom (both effective and ineffective). As outlined in Chapter 4, over 80% of all participants indicated they would likely implement 11 out of the 12 listed instructional practices. At first glance, it appears as if the participants were responding indiscriminately to the prompt. However, when speaking to interview participants about instructional practices, several of the individuals stated that teaching is full of "trial and error," and they were willing to "try anything" to see what works for their students. Although education professors may stress the importance of selecting and implementing research-based practices, teachers tend to be very practical about the decisions they make in the classroom. This sentiment was aptly summarized by Daniel and Chew (2013):

> Teachers are pragmatic because they have to develop pedagogy in the absence of complete knowledge about how their students learn. Thus, they often base their

> pedagogy on intuition, informal observations from their own experience, and beliefs that have no overt empirical foundation. (p. 363)

Moving forward, it is important to recognize the dissonance that teachers experience in the classroom. They are trained to implement established effective practices, yet they are also trying to just figure out “what works” for individual learners. This phenomenon holds significant import for confronting how to approach instruction in education neuroscience literacy.

Relation between Demographic Factors, Survey Responses, and Likelihood to Implement Instructional Practices

In this section, I present interpretations of associations related to perceptions of neuromyths in the following key areas: (a) likelihood to implement instructional practices, (b) number of completed education courses, (c) number of completed science courses, and (d) self-reported levels of preparedness with regards to educational neuroscience literacy.

Responses to neuromyth prompts and likelihood to implement instructional practices. As outlined in Chapter Four, I examined the strength of the relationship between correct responses to neuromyths prompts and practice differential (the degree to which participants rated effective instructional practices higher than ineffective practices). There was a moderate, positive relationship between these items. I ran the same correlation analysis for participants’ correct responses to general brain knowledge questions. There was not a significant correlation between general brain knowledge and practice differential. These findings suggest that participants who are aware of neuromyths are slightly more likely to implement effective instructional practices, and intimate that awareness of neuromyths as opposed to general brain knowledge is more important when predicting likelihood of implementing effective instructional practices.

I also conducted Krusakal-Wallis tests to whether likelihood to implement a related instructional practice differed as a function of responses to corresponding neuromyth items (“correct,” “incorrect,” and “do not know”) . It was encouraging to discover that in regards to both learning styles and hemispheric dominance, Kruskal-Wallis tests showed a statistically significant difference in likelihood to implement modality training and hemispheric dominance across the three response types (“correct,” “incorrect,” and “do not know”). Participants who correctly identified the neuromyth statements related to modality training and hemispheric dominance were least likely to implement the corresponding instructional practices, and participants who incorrectly identified the neuromyth statements were most likely to implement the corresponding instructional practices. Again, these findings suggest that an awareness of neuromyths may assist teachers in selecting effective instructional practices more frequently than ineffective practices. These data provide support for the argument that in-service and pre-service teachers should be provided with training to improve their educational neuroscience literacy.

Number of completed education courses. A moderate, positive correlation was demonstrated between number of education courses and total correct survey responses. There was also a moderate, negative significant correlation between number of education courses and “do not know” responses. Specific to neuromyths, there was a moderate, positive correlation between number of education courses and correct responses. These findings suggest that education courses could be associated with identification of neuromyths and general knowledge of the brain, learning, and behavior. This highlights the overall importance and potential impact of the quality of courses provided in teacher education programs.

Number of completed science courses. There was a moderate, positive correlation between number of science courses and correct total survey responses. Specific to neuromyths, there was a moderate, positive correlation between number of science courses and incorrect responses. These findings suggest that science courses may assist participants in correctly answering questions about general brain knowledge; however, science courses do not prepare participants to identify neuromyths. Science courses may provide students with a foundation in science literacy, however, they do not appear to provide students an exposure to instructional pedagogy. Therefore, a background in science does not appear to help students identify pseudoscience within an education context. Findings indicate that education courses, not science courses, are associated with a stronger foundation in educational neuroscience.

Self-reported levels of preparedness in educational neuroscience literacy. I ran a correlation analysis to examine the strength of the relationship between perceived level of preparedness and responses to neuromyth statements. Interestingly, I found a moderate positive correlation between perceived level of preparedness and *incorrect* responses to neuromyths statements. Similar results were demonstrated among participants from the UK and the Netherlands (Dekker et al., 2012). Such findings appear counterintuitive. It seems logical that there would be a positive correlation between perceived level of preparedness and correct answers. These findings seem to support the adage, “a little bit of knowledge is a dangerous thing.” On occasion, when an individual possesses a cursory understanding of an idea, they tend to overestimate their knowledge and develop a false sense of confidence. This problematic behavior has long been a focal point of study within the discipline of knowledge management, and practical examples of its deleterious effects are evidenced in a wide range of fields, including medicine (Cabana, 2015) and business (Vendler, Toft-Kehler, Wennberg, & Kim, 2016). It is not surprising that teacher candidates are also affected by this phenomenon. They are regularly exposed to anemic scientific news in the popular press, and as interview participants conveyed, they receive cursory information about neuromyths in their education programs. Collectively, these scraps of information can convince them that they have a better understanding of neuroscience and education than they actually do, and this may unfortunately lead them to make poor instructional choices due to unwarranted confidence. Teacher candidates should be provided with a more thorough and systematic training within their education courses to ameliorate potential deleterious classroom practices founded upon a false sense of knowledge.

Implications for Practice

In the previous section, I outlined several areas that should be addressed to combat the persistent neuromyths among pre-service and in-service teachers. In the following section, I provide implications of the current findings for future practice.

Neuroeducation Literacy

Based upon the findings of this study, and supported by data from extant studies on neuromyths, it appears that pre-service (and in-service) teachers struggle with identifying instructional practices that are founded upon neuromyths and are not supported by empirical evidence. To ameliorate this deficit it is perhaps best to start with small and simple steps. There are many disparate education programs across the country. Within these programs, departments tend to offer prescriptive courses, must adhere to strict accreditation guidelines that dictate course content, and professors have a limited amount of freedom to add complementary units on neuroscience and education. This is the current reality of teacher preparation programs.

It is important to acknowledge the current realities of the parameters in which colleges of education exist. Given these realities, I suggest adopting specific strategies that instructors can easily implement within their set curriculum. A fine example of one such strategy is the use of IRIS modules. These interactive, online modules are federally funded by the United States Department of Education's Office of Special Education Programs. These self-contained units provide teacher education candidates with a broad understanding of a range of topics (e.g., progress monitoring, assistive technology, collaboration). Teacher educators can assign these modules to their students without disrupting the scope and sequence of their courses. The development and implementation of modules related to neuroeducation is one simple and effective method to enhance existing education courses. An analysis of extant studies on neuromyths definitively reveals that in-service and pre-service teachers believe in three prominent neuromyths: modality dominance, hemispheric dominance, and perceptual motor training (e.g., Karakus et al., 2015; Tardif et al., 2015). Additionally, data indicate teacher candidates have a poor understanding of the neurophysiology of the brain as it relates to specific exceptionalities (e.g., Dekker et al., 2012). I propose that current leaders in neuroeducation develop and disseminate modules that cover these specific topics. Moreover, modules can be tailored to meet the needs of specific education courses. For example, education courses on reading can include modules about the neurophysiology of dyslexia and current neuroscience research about effective practices. Behavior management courses can incorporate modules about the neurophysiology of ADHD and recent findings for effective behavioral interventions. This simple approach can help professors provide their students with an introduction to neuroeducation, and help reduce the pervasiveness of educational neuromyths and pseudoscience.

Another study finding underscores the importance of semantics in teacher education programs. Many of the interview participants stated in their quantitative responses that they supported the use of learning styles as an instructional approach. However, during follow-up discussions, it became clear they did not fully understand the term “learning styles” in the same manner as researchers. When asked to describe how they would incorporate learning styles in the classroom, they generally spoke of the importance of providing audio and visual supports for all learners. These are acceptable practices regularly promoted within education courses. Additionally, when prompted to explain why they believed perceptual motor training was an effective practice, the majority of respondents elaborated on the importance of incorporating movement in the classroom. Taking time for “brain breaks” or stressing the importance of physical activity does not indicate support for perceptual motor training. Moreover, several interview participants used the terms UDL, learning styles, differentiation, and culturally-responsive instruction interchangeably.

It is difficult to measure teachers’ perceptions of neuromyths if discussions are muddled by the use of vague or incorrect terminology. Accordingly, teacher educators should be mindful to speak articulately and consistently about instructional practices and ideas. They should model the importance of linguistic precision for their students. More importantly, if a teacher candidate casually talks about learning styles or multiple intelligences for learning during an education course, instructors need to take the time to address their statements and engage in a discussion about what these terms mean. When instructors allow seemingly benign neuromyth statements to go unchecked in the classroom, they are inadvertently maintaining the pervasiveness of these specious ideas and practice. In "Teachers' Beliefs and Messy Constructs," Pajares (1992) stressed the importance of clear elocution during instruction and the long-term impact messy communication may pose for instruction.

In addition to these recommendations, several established programs and approaches could be used to assist teacher educators, in-service teachers, and pre-service teachers to improve their understanding of the relationship between neuroscience and learning. A leading scholar in this field, Janet Dubinsky (2010), developed a neuroscience education program for preK-12 teachers. The purpose of the program was to disseminate knowledge about the connection between neuroscience and learning to classroom teachers and their students. The program, Brain U, introduces teachers to basic neuroscience knowledge. During a two-week seminar, teachers learn about the nervous system and neural plasticity. The seminars consist of observations, hands-on activities, experimentations, and discussions. A unique component of this program is that teachers engage in activities appropriate for classroom use. As a result, teachers are able to share their recently acquired knowledge with their classroom students, thereby increasing dissemination of educationally relevant neuroscience principles. The program resulted in significantly positive effects in both teachers' and students' knowledge of educationally relevant neuroscience (Dubinksy, 2010). Information about this program can be accessed at http://www.cehd.umn.edu/stem/Research/BrainU/default.html. This program can be replicated in teacher education programs to assist teacher educators in preparing their teacher candidates in becoming more knowledgeable about educationally relevant neuroscience.

Another resource on neuroscience, cognition, and education has been made publicly available by the Deans for Impact. This consortium of deans regularly conducts research studies and releases briefs aimed at improving the quality of instruction at colleges of education across the United States. This group published a document titled, the "Science of Learning" (2015). This document summarized current research on how students learn and made practical connections to classroom instruction. The purpose of this article is to provide teacher educators and classroom teachers with the most recent and relevant research about the scientific underpinnings of learning. The document identified six established neurocognitive principles along with practical implications for the classroom. This resource is currently available at https://deansforimpact.org/wp-content/uploads/2016/12/The_Science_of_Learning.pdf.

Another valuable resource can be found in the text, *Mind, Brain, and Education Science: A Comprehensive Guide to the New Brain-Based Teaching* (Tokuhama-Espinosa, 2011). In this informative introductory text to neuroeducation, Tokuhama-Espinosa provided a detailed table comparing educational neuroscience claims from the OECD to the criteria for effectiveness developed by the "Best Evidence Encyclopedia" and "What Works Clearinghouse." This table can be incorporated into teacher education programs when discussing evidence-based practices with regards to neuroscientific support. Lastly, David Sousa (2016), an educational neuroscientist, has written an explanatory text specific to neuroscience and students with exceptionalities. This text can provide education professors and special education teachers with a strong foundation of the implications of neuroeducation for students with exceptionalities.

Scientific Literacy

Ideally, teacher preparation programs will begin to include education neuroscience literacy into their curricula. However, given the realities and restrictions placed upon these programs, this is an ambitious goal. In addition to supporting the inclusion of educational neuroscience literacy within teacher preparation courses, programs should strengthen their commitment to the use of empirical evidence in assessing sound instructional practices. Thanks to the evidence-based practice movement, teacher educators and in-service and pre-service teachers are becomingly increasingly cognizant of the importance of implementing instructional strategies and behavioral interventions that have sound empirical evidence (Torres, Farley, & Cook, 2014). Torres and colleagues (2014) highlighted the importance of implementing evidence-based practices, and provided readers with ten tips for successful implementation. This article is indicative of the changing focus among researchers and practitioners to base their practice on empirically sound instruction. I recommend that teacher educators share articles like this with their teacher candidates to encourage them to think about the importance of using evidence-based practices, and to provide them with the practical guidance for implementing these practices in the classroom. The rationale for using evidence-based practices is to ensure that teachers are implementing instructional practices that are based on research. If teachers are trained to seek out evidence-based practices, this could mitigate the erroneous inclusion of practices based on neuromyths, and improve teachers' overall scientific literacy.

Other helpful approaches for teacher candidates to increase their scientific literacy have long been available. For example, Sagan (1995) and Trugan (1978) stressed the importance of considering (a) "Unfalsifiability," a key characteristic of most pseudoscience (e.g., facilitated communication); (b) lack of self-correction, a hallmark of pseudoscience (e.g., we only use 10% of our brains); (c) confirmation bias; (d) the importance of peer reviewed sources; (e) "Absence of connectivity," most valid theories build upon or are connected to prior bodies of research; (f) the use of hypertechnical language, pseudoscience is often shrouded in specialist terminology; (g) *Ad antequitatem fallacy*, the phenomenon of granting credibility to an idea merely because it has been around for a long time; and (h) extraordinary claims, extraordinary claims require extraordinary evidence. Additionally, Travers (2016) recently provided special education teachers with recommendations for distinguishing between effective, unproven, and pseudoscientific practices. This practitioner-friendly resource offers practical advice for making informed instructional decisions, and can help improve the scientific literacy of pre-service and in-service teachers. Improving the scientific literacy of special education teachers can combat the pervasiveness of neuromyths within education.

Limitations

The findings of this study should be considered within the context of some important limitations to the study. I this study I used a convenience, purposive, and non-probability sample. The sample size for the quantitative survey component was *N*=131; the sample size for the qualitative interview component was *n*=6. The limited sample size, along with the non-representative sampling, decreases the generalizability of the study findings and diminishes statistical power. Additionally, study participants included individuals from the Midwest, South, and West; I was not able to secure any study participants from the Northeast. As such, not all regions of the United States are represented. The interview participants also were self-selected, and this creates the possibility of bias within the study. Specifically, self-reported beliefs are subject to social desirability and may not correspond with actual beliefs and/or behaviors. It should also be noted that data collected for this study were self-reported, and the reliability of the survey instrument was on the low-level of acceptable ($r = .67$). During data analysis, it became apparent that the qualitative data was invaluable for contextualizing the quantitative survey responses. In order to gather more robust and generalizable data about the implications of neuromyths, future researchers should conduct interviews with more participants, and to interview participants more than once. Finally, the study design does not permit any causal inferences. For example, although more educational coursework is positively associated with greater accuracy identifying neuromyths, such coursework may not have caused improved accuracy. Experimental research should be conducted to examine variables that cause accurate identification of neuromyths.

Recommendations for Future Research

Present findings, in addition to data from related studies, clearly establish a need to address the prevalence of neuromyths among in-service and pre-service teacher candidates. From these studies, a wealth of data have been collected about teachers' perceptions of neuromyths, the most commonly believed neuromyths, and teachers' beliefs about instructional practices as informed by neuromyths. This research has established baseline knowledge that is valuable and necessary. However, it is time to move beyond survey studies of teacher beliefs.

Future research studies should more directly examine the extent to which neuromyths influence actual classroom instruction. This necessitates different research methods than the extant surveys. The information gathered during the qualitative interviews in this study provided preliminary information on understanding the dissemination of neuromyths and the potential influence of these myths on classroom practice. I suggest that large-scale qualitative studies are needed to more fully understand the mechanisms that continue to support and perpetuate neuromyths in education. Critically, these qualitative studies should include pre-service teachers, in-service teachers, *and* education professors. To date, no known study has explicitly explored professors' knowledge of neuromyths, or how they address educational neuroscience literacy in the classroom.

Additionally, future research should include behavioral observations. All of the extant studies focus on participants' knowledge and self-reported predicted behavior. In order to assess the effects of neuromyths in education, it is critical to observe what is actually occurring in the classroom (e.g., teacher and student behavior). Along these lines, there is a great need for more intervention studies (i.e., Dubinksy, 2010). Future studies could develop neuroeducation curriculum, provide teachers with training, assess their instructional decisions in the classroom, and monitor student performance.

Lastly, future research should involve a stronger collaboration between professionals in the fields of neuroscience and education. Fortunately, scholars have been theorizing on how to improve collaboration between these seemingly disparate fields. For example, Devonshire and Dommett (2010) asserted neuroscientists need to be trained in science communication, so their work is accessible to those outside of their field. Additionally, they suggested that neuroscientists should provide separate, more broadly accessible reports based on their articles published in peer-reviewed research journals. They also recommended that educators receive basic training in neuroscience so they are able to be critical and discerning consumers of neuroscience research, discriminating between neuromyths and scientifically valid concepts appropriate for use in the classroom. These seemingly simple, yet practically challenging, recommendations can help pave the way for more fruitful collaboration between educators and neuroscientists.

Conclusion

The purpose of this mixed-methods explanatory study was to examine pre-service teachers' perceptions of neuromyths; their general knowledge about the brain, learning, and behavior; and their self-reported likelihood to implement an array of instructional practices. Additionally, this study explored the associations between participants' perceptions and knowledge, demographic variables, and their likelihood to implement effective versus ineffective practices. Compared to extant studies on neuromyths, this study is unique in that participants were pre-service special education teachers from the United States. Prior studies have not included participants from the United States, nor did they include special education teachers.

Similar to related studies on neuromyths, participants of this study reported high levels of beliefs in neuromyths, and indicated they would likely implement an array of neuromyth-based instructional practices in the classroom. However, findings from follow-up interviews suggest participants might have misinterpreted some of the neuromyth statements (e.g., some participants considered the general provision of audio and visual supports as teaching to specific learning styles). To address this issue, future research should include extensive qualitative interviews of pre-service and in-service teachers, along with classroom observations of instructional practices.

Similar to other studies, participants indicated they were interested in learning more about neuroscience and education. However, participants expressed their interest is contingent upon the provision of specific instructional practices based on neuroscience research. Currently, there is a need to improve the quality of translational research between neuroscience and education. Future research should focus on articulating and disseminating neuroscience findings that can explicitly support the development and implementation of effective instructional practices.

It was also clear that participants did not fully understand the terminology used to discuss effective versus ineffective practices. For example, participants stated they believed in the importance of teaching to specific learning styles. Yet, when prompted, they discussed the importance of UDL and differentiation. Teacher educators are providing their candidates with effective tools to use in the classroom, but there is ambiguity amongst candidates about the appropriate language to describe specific practices and approaches. Furthermore, it is clear that candidates still need support in identifying reliable sources of information for evidence-based practices, and tips for developing this ability to be critical consumers of brain-based programs.

Finally, a moderate positive correlation was found between number of education courses completed and “correct” responses to neuromyth statements. This suggests that teacher education courses might help to improve pre-service teachers’ educational neuroscience literacy and prevent the implementation of instructional practices based upon neuromyths. A concerted effort, led by specialists in neuroeducation, should address the needs of teacher educators in their efforts to provide students with sound instruction related to neuroscience, education, and instruction.

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Appendix A

Neuroeducation Institutes, Societies, Academic Programs, Publications, and Conferences

Institutes

Brain and Mind Research Institute (University of Sydney)

Brain Institute (University of Utah)

Brain Institute (Vanderbilt University)

Queensland Brain Institute

Stockholm Brain Institute

Societies

Australian Neuroscience Society

Belgian Society for Neuroscience

Brain, Neuroscience, and Education Special Interest Group of the American Educational Research Association

Centre for Brain & Learning (Amsterdam)

International Mind, Brain, and Education Society

International Brain Research Organization

Academic Programs

Brain and Creativity Institute (University of Southern California)

Centre for Neuroscience and Education (Bristol University)

Master's Program in Mind, Brain, and Education (Harvard University)

Mind, Brain Institute (Johns Hopkins University)

MIT Brain and Cognitive Sciences Programs

Program in Psychology and Neuroscience in Education (Cambridge University)

Southwest Center for Mind, Brain Education (University of Texas at Austin)

Stanford Psychiatry and Neuroimaging Laboratory

Publications

Mind, Brain, and Educational Journal

Trends in Neuroscience and Education

Educational Neuroscience

Conferences

Learning & the Brain Conferences

International Mind, Brain, and Education Society

Appendix B

Educationally Relevant Neuromyths (OECD, 2002)

1) Short bouts of coordination exercises can improve integration of left and right hemisphere brain function.
2) Learning problems associated with developmental differences in brain function cannot be remediated by education.
3) Children must acquire their native language before a second language is learned. If they do not do so, neither language will be fully acquired.
4) It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement.
5) We only use 10% of our brain.
6) Differences in hemispheric dominance (left brain, right brain) can help explain individual differences amongst learners.
7) There are critical periods in childhood after which certain things can no longer be learned.
8) Individuals learn better when they receive information in their preferred learning style (e.g., visual, auditory, kinesthetic).
9) Environments that are rich in stimulus improve the brains of pre-school children.
10) Children are less attentive after consuming sugary drinks and/or snacks.
11) Exercises that rehearse coordination of motor-perception skills can improve literacy skills.

12) If pupils do not drink sufficient amounts of water (= 6-8 glasses a day) their brains will shrink.

Appendix C

Learning and the Brain Survey

Part One
Directions: The following is a list of instructional strategies or approaches. Please indicate your likelihood of implementing each one of these in the classroom.
----

1. Modality Training: *Providing instruction for children based on their preferred modality (visual, auditory, kinesthetic)*

Definitely Will Not **Probably Will Not** **Probably Will** **Definitely Will**

2. Applied Behavior Analysis: *Systemic application of behavioral principles (e.g., modifying antecedents and consequences) to change student learning and behavior*

Definitely Will Not **Probably Will Not** **Probably Will** **Definitely Will**

3. Multiple Intelligences: *Providing instruction f tailored to students' strongest area of intelligence (musical-rhythmic, visual-spatial, verbal-linguistic, logical-mathematical, bodily-kinesthetic, interpersonal, intrapersonal, and naturalistic)*

Definitely Will Not **Probably Will Not** **Probably Will** **Definitely Will**

4. Formative Evaluation: *Systematically measuring student progress toward instructional goals and modifying instruction as necessary to assist students in meeting specific goals*

Definitely Will Not **Probably Will Not** **Probably Will** **Definitely Will**

5. Perceptual Motor Training: *Programs designed to improve academic skills by enhancing sensory and motor skills (e.g., Brain Gym®)*

Definitely Will Not **Probably Will Not** **Probably Will** **Definitely Will**

6. Mnemonic Strategies: *Structured strategies to help students retain and recall information*

Definitely Will Not **Probably Will Not** **Probably Will** **Definitely Will**

7. Psycholinguistic Training: *Determining difficulties in auditory and visual-motor receptive, integrative, and expressive abilities and improving academic skills by remediating the weakness*

Definitely Will Not Probably Will Not Probably Will Definitely Will

8. Neurological Repatterning: *Students who skip developmental stages in motor development are provided with opportunities to master the undeveloped skills to address cognitive and behavioral deficits*

Definitely Will Not Probably Will Not Probably Will Definitely Will

9. Direct Instruction: *Teacher-directed learning with sequenced instruction including modeling, guided practice, independent practice, and immediate and corrective feedback with high levels of student responding*

Definitely Will Not Probably Will Not Probably Will Definitely Will

10. Learning Style Inventories: *Assessments used to identify the learning modality of students (visual, auditory, kinesthetic)*

Definitely Will Not Probably Will Not Probably Will Definitely Will

11. Hemispheric Dominance Training: *Tailoring instruction to address the different learning needs of "left-brain" and "right brain" learners*

Definitely Will Not Probably Will Not Probably Will Definitely Will

12. Multiple Intelligence Questionnaires: *Assessments used to identify the intelligence modality of individual students (musical-rhythmic, visual-spatial, verbal-linguistic, logical-mathematical, bodily-kinesthetic, interpersonal, intrapersonal, and naturalistic)*

Definitely Will Not Probably Will Not Probably Will Definitely Will

Part Two

Directions:

For each of the following statements please select "incorrect," "correct," or "do not know."

---

1. There are critical periods in childhood after which certain things can no longer be learned.
    a. Correct
    b. Incorrect
    c. Do not know
2. Differences in hemispheric dominance (left brain, right brain) can help explain individual differences amongst learners.
    a. Correct
    b. Incorrect
    c. Do not know
3. We use our brains 24 hours a day.
    a. Correct
    b. Incorrect
    c. Do not know
4. Children must acquire their native language before a second language is learned. If they do not do so, neither language will be fully acquired.
    a. Correct
    b. Incorrect
    c. Do not know
5. If students do not drink sufficient amounts of water (=6–8 glasses a day) their brains shrink.
    a. Correct
    b. Incorrect
    c. Do not know
6. It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement.
    a. Correct
    b. Incorrect
    c. Do not know
7. When a brain region is damaged other parts of the brain can take up its function.
    a. Correct
    b. Incorrect
    c. Do not know
8. We only use 10% of our brain.
    a. Correct
    b. Incorrect
    c. Do not know
9. The left and right hemispheres of the brain always work together.
    a. Correct
    b. Incorrect
    c. Do not know

10. The brains of boys and girls develop at the same rate.
    a. Correct
    b. Incorrect
    c. Do not know
11. Brain development has finished by the time children reach secondary school.
    a. Correct
    b. Incorrect
    c. Do not know
12. Information is stored in the brain in a network of cells distributed throughout the brain.
    a. Correct
    b. Incorrect
    c. Do not know
13. Learning is due to the addition of new cells in the brain.
    a. Correct
    b. Incorrect
    c. Do not know
14. Individuals learn better when they receive information in their preferred learning style (e.g., auditory, visual, kinesthetic).
    a. Correct
    b. Incorrect
    c. Do not know
15. Boys have bigger brains than girls.
    a. Correct
    b. Incorrect
    c. Do not know
16. Learning occurs through modification of the brains' neural connections.
    a. Correct
    b. Incorrect
    c. Do not know
17. Academic achievement can be affected by skipping breakfast.
    a. Correct
    b. Incorrect
    c. Do not know
18. Normal development of the human brain involves the birth and death of brain cells.
    a. Correct
    b. Incorrect
    c. Do not know
19. Mental capacity is hereditary and cannot be changed by the environment or experience.
    a. Correct
    b. Incorrect
    c. Do not know
20. Vigorous exercise can improve mental function.
    a. Correct
    b. Incorrect

   c. Do not know
21. Environments that are rich in stimulus improve the brains of pre-school children.
   a. Correct
   b. Incorrect
   c. Do not know
22. Children are less attentive after consuming sugary drinks and/or snacks.
   a. Correct
   b. Incorrect
   c. Do not know
23. Circadian rhythms ("body-clock") shift during adolescence, causing students to be tired during the first lessons of the school day.
   a. Correct
   b. Incorrect
   c. Do not know
24. Regular drinking of caffeinated drinks reduces alertness.
   a. Correct
   b. Incorrect
   c. Do not know
25. Exercises that rehearse coordination of motor-perception skills can improve literacy skills.
   a. Correct
   b. Incorrect
   c. Do not know
26. Extended rehearsal of some mental processes can change the shape and structure of some parts of the brain.
   a. Correct
   b. Incorrect
   c. Do not know
27. Individual learners show preferences for the mode in which they receive information (e.g., visual, auditory, kinesthetic).
   a. Correct
   b. Incorrect
   c. Do not know
28. Learning problems associated with developmental differences in brain function cannot be remediated by education.
   a. Correct
   b. Incorrect
   c. Do not know
29. Production of new connections in the brain can continue into old age.
   a. Correct
   b. Incorrect
   c. Do not know
30. Short bouts of coordination exercises can improve integration of left and right hemispheric brain function.
   a. Correct
   b. Incorrect

c. Do not know

31. There are sensitive periods in childhood when it is easier to learn things.
    a. Correct
    b. Incorrect
    c. Do not know

----

32. How interested are you in scientific knowledge about the brain and its influences on learning?
    a) strongly disinterested
    b) somewhat disinterested
    c) neutral
    d) somewhat interested
    e) strongly interested
33. What is your main source for information about learning and the brain? Mark all that apply
    a) popular press and media
    b) scholarly journals
    c) university courses
    d) online sources: please list sites
    e) other:____
34. Courses you have taken in the College of Education have provided you with information about the structure and function of the brain as it relates to learning.
    a) strongly disagree
    b) somewhat disagree
    c) neutral
    d) somewhat agree
    e) strongly agree
35. In what educational area are you seeking licensure?
    a) special education
    b) dual preparation (general education and special education)
    c) other: Please specify
37. Including the courses you are taking this semester, how many education courses have you taken?
38. Please list any science or psychology courses you have taken:______________________

Appendix D

Semi-Structured Interview Questions

1) What are your thoughts about specific neuromyths (e.g., modality training, perceptual motor training, hemispheric, etc.)?

2) Do you plan on implementing any of these practices in the classroom? If so, what would that look like?

3) Did you learn about these practices in your education courses?

4) Have you seen your mentor teacher use any of these practices?

5) Do you think it is important to know about the structure and function of the brain as it relates to learning? Why or why not?

6) What other instructional approaches do you feel are effective? Why?

7) What instructional approaches do you believe are not effective? Why?

8) How important is it to you to verify the research-base for an instructional practice you use in the classroom?

9) Would you like to learn more about learning and the brain? In what ways can your teacher preparation program assist you in this area?

Appendix E

Survey Invitation

Subject Line: Neuroscience and Education Survey, Request for Input

Aloha Education Professor,

Presently, findings in neuroscience are increasingly able to inform educational research and practice. Background information about future special educators' knowledge and attitudes related to neuroscience and education is valued.

The purpose of this survey is to assess pre-service teachers' perceptions of neuroscience and education, with specific attention given to "neuromyths" (commonly held false beliefs about neuroscience). The data collected from this survey will assist teacher education programs in developing effective teacher preparation curricula related to neuroscience and education.

Please consider administering this survey to your students as part of this research study.

If you are interested, I will provide you with complete information about project, the survey, and administration procedures.

Thank you for your time,

Amy Ruhaak