The Role of an Educational Psychology Course in Enhancing Neuroscience Literacy and Reducing Beliefs in Neuromyths in US and Korean Pre-Service Teachers

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Abstract

Although educators are increasingly interested in applying neuroscience findings to educational practice, their understanding about the brain often lags behind their enthusiasm for the brain. This study evaluated the effect of an introductory educational psychology course for enhancing the *neuroscience literacy* and reducing beliefs in *neuromyths* of pre-service teachers in the US and Korea. The results showed that the educational psychology course enhanced neuroscience literacy, although it did not reduce beliefs in neuromyths. With respect to moderating factors, the results showed that the information sources from which participants learned about neuroscience findings had a marginal effect on neuroscience literacy, whereas prior coursework had no effect on neuroscience literacy and belief in neuromyths. With respect to attitudes towards bridging between education and neuroscience, pre-service teachers had positive views about the general use and specific application of neuroscience research to solve educational problems. In sum, the field of educational psychology provides another interdisciplinary ground for bridging education and neuroscience.

Table of Contents

Abstract …………………………………………………………………………… i

List of Tables ………………………………………………………………………… iv

List of Figures ……………………………………………………………………….. v

1 Introduction ………………………………………………………………………. 1

2 Literature Review …………………………………………………………………. 4

2.1 Public interest in neuroscience findings …………………………… 4

2.2 Educator interest in neuroscience findings ………………………... 7

2.3 Why educators must know about neuroscience …………………… 9

2.4 Efforts in bridging education and neuroscience …………………… 13

2.5 Neuroscience literacy ……………………………………………… 15

2.6 Neuromyths ………………………………………………………... 17

2.7 Measuring neuroscience literacy and beliefs in neuromyths ………. 20

2.8 Educators' views on the role of neuroscience in education ……….. 22

3 The Current Study ……………………………………………………….. 24

4 Method ……………………………………………………………………… 26

4.1 Participants ………………………………………………………… 26

4.2 Materials …………………………………………………………… 26

4.2.1 Neuroscience knowledge survey ……………………… 26

4.2.2 Introductory educational psychology course ………….. 29

4.3 Procedure ………………………………………………………….... 30

4.4 Data analysis and design …………………………………………… 31

5 Results 33

5.1 Neuroscience literacy 33

5.2 Beliefs in neuromyths 35

5.3 Background factors 38

5.4 Attitudes about applying neuroscience findings to educational practice 41

6 Discussion 44

6.1 Increasing neuroscience literacy 45

6.2 Decreasing beliefs in neuromyths 47

6.3 Background factors affecting neuroscience literacy 49

6.4 Increasing positive attitudes about educational neuroscience 51

6.5 Opportunities and challenges for bridging education and neuroscience 52

6.6 Limitation and future directions 55

References 57

Appendix A: Survey questionnaire 71

Appendix B: Course syllabus 74

Appendix C: Distribution of responses for each correct statement 75

Appendix D: Distribution of responses for each incorrect statement 79

List of Tables

Table		Page
1.	Effect of taking an introductory educational psychology course on the neuroscience literacy of pre-service teachers in the US and Korea………	34
2.	Neuromyths believed by 50% or more of US or Korean pre-service teachers at pre or post-test……………………………………………	36
3.	Effect of taking biology or neuroscience courses on the overall neuroscience literacy score at each time point of each group……………	39
4.	Effect of taking biology or neuroscience courses on the overall neuromyth items score at each time point of each group…………………	39
5.	Main information sources about neuroscience in US and Korean pre-service teachers…………………………………………………………	40
6.	General attitudes about applying neuroscience findings to support educational practice in US and Korean pre-service teachers……………....	42
7.	Specific attitudes about applying neuroscience findings to solve particular educational problems in US and Korean pre-service teachers….	43

List of Figures

Figure		Page
1.	Neuroscience literacy score in US and Korean pre-service teachers ……	33
2.	Neuromyths score in US and Korean pre-service teachers…………	37
3.	The three levels of framework for bridging education and neuroscience	54

1 Introduction

There is a growing interest in applying neuroscience findings to educational theory, practice, and policy (Dubinsky, Roehrig, & Varma, 2013; Heckman, 2008; Hinton, Miyamoto, & Della-Chiesa, 2008; Goswami, 2006). That the brain is plastic – malleable and flexible depending on environmental stimuli – highlights the importance of educators' roles in optimizing the brain function. Neuroimaging data increase educators' appetites for scientific evidence informing their educational practice. More generally, the remarkable progress in neuroscience over recent decades has prompted great interesting in bridging education and neuroscience.

Many educators believe that understanding how the brain works is informative for designing educational activities and delivering instruction (Pickering & Howard-Jones, 2007). However, their understanding of the brain often lags behind their enthusiasm for the brain. Knowledge about the basic terminology of brain structure and neuroimaging techniques is essential for understanding and critically evaluating books, reports, and articles about the brain. Without knowing about 'synapse' – the gap between the axon of a sending neuron and the dendrite of a receiving neuron – educators cannot understand information processing and communication in the brain and how they change over brain development. Nor can they understand the results of neuroscience studies without knowing about different neuroimaging techniques such as EEG (Electroencephalography) / ERPs (Event Related Potentials), MRI (Magnetic Resonance Imaging), fMRI (functional MRI), MEG (Magnetoencephalography), PET (Positron Emission

Tomography), TMS (Transcranial Magnetic Simulation), VBM (Voxel-based Morphometry), and DTI (Diffusion Tensor Imaging).

Understanding brain function and neuroscience (particularly neuroimaging) methodologies is critical for appropriately analyzing, interpreting, and applying neuroscience findings to educational practice. Understanding brain plasticity across the lifespan is also important for educators to recognize the importance of lifelong learning (Bruer, 1999). Understanding neuroimaging methodologies including localization of activation, thresholding, subtraction contrasts, and the dangers of reverse inference is important if educators are to apply neuroscience findings in an effective and responsible manner.

However, educators have few opportunities to learn information about the brain, and thus to derive sound educational implications of neuroscience research. To put them in position to apply neuroscience findings to educational practice, we need to enhance their *neuroscience literacy* – their knowledge about neuroscience terminology, brain structure, and neuroimaging techniques, and their understanding of key brain functions and neuroimaging methodologies (Dillon, 2009; Zardetto-Smith et al., 2002). In the absence of knowledge about the brain and an understanding of how to interpret neuroscience data, educators' enthusiasm for neuroscience findings has resulted in the rise of widespread *neuromyths* (Geake, 2008). These include misconceptions about the neural evidence for and educational importance of preferred learning styles, hemispheric dominance, the effect of coordination exercises on "integrating" brain function (e.g., Brain Gym), and so on (Dekker et al., 2012; OECD, 2002).

One vehicle for enhancing neuroscience literacy and reducing beliefs in neuromyths of pre-service teachers is through the introductory educational psychology course that is part of most teacher training curricula. This is because this course introduces the scientific method, which may be new to many pre-service teachers, and covers concepts from cognitive and developmental psychology that are also central to neuroscience research. The current study evaluated the effect of an introductory educational psychology course for enhancing neuroscience literacy and reducing beliefs in neuromyths of pre-service teachers. The sample included US and Korean groups to enable us to look for cross-cultural differences. We also investigated whether differences in prior coursework in biology or neuroscience and difference in the information sources consulted influenced neuroscience literacy and beliefs in neuromyths. Finally, we examined pre-service teachers' attitudes towards bridging between education and neuroscience. Based on these findings, we offer a framework for bridging education and neuroscience.

2 Literature Review

2.1 Public interest in neuroscience findings

> *"The human brain, a 3-pound mass of interwoven nerve cells that controls our activity, is one of the most magnificent – and mysterious – wonders of creation. The seat of human intelligence, interpreter of senses, and controller of movement, this incredible organ continues to intrigue scientists and layman alike."*
>
> Bush (1990, Proclamation 6158 of July 17)

The declaration of 1990s as the "Decade of the Brain" accelerated the public's interest in neuroscience findings. Research on the genetics of brain function and development as well as the maturation of neuroimaging technologies were breathlessly reported by the media. Nowadays, fMRI images are routinely used to communicate new information about the brain to the general public. President Obama's recent launch of the "BRAIN" initiative (Brain Research through Advancing Innovative Neurotechnologies) – *a bold new research effort to revolutionize our understanding of the human mind and uncover new ways to treat, prevent, and cure brain disorders like Alzheimer's, schizophrenia, autism, epilepsy, and traumatic brain injury* – promises to continue to feed the public's interest in neuroscience findings (Insel, Landis, & Collins, 2013).

Press coverage between 1994 and 2004 mostly focused on research on adult brains and on the expected health-related benefits of neuroscience findings, for example for the diagnosis and treatment of dementia and Alzheimer's diseases (Racine, Bar-Ilan, & Illes, 2006). The public also showed interest in understanding brain function more generally. Herculano-Houzel (2002) reported an on-line survey showing that the public was even more interested in neuroscience findings about memory, consciousness, learning, and emotion than findings related to health issues.

More recently, O'Connor, Rees, and Joffe (2012) investigated the reporting of neuroscience discoveries by the popular press in the UK. The results showed that brain optimization, psychopathology, and basic function were most frequently reported to the public. These results partially overlap with scientists' own interests in primary brain functions such as learning, memory, attention, emotion, language, and consciousness. Behrens et al. (2012) examined published scientific articles in the BrainMap database (http://www.brainmap.org), finding that cognition, memory, emotion, attention, and language were the most frequent keywords. These studies attest to the general interest in both basic brain function and in maintaining brain fitness for both health and non-health reasons.

The public has become increasingly interested in the feasibility of applying neuroscience findings to other fields of social science such as law, economics, and politics. This has been accompanied by the emergence of neuroethics, as the application of neuroimaging technologies to detect lies, enhance cognitive performance, and "improve" consumer advertising raises new more questions: *Should* we do what we increasingly *can* do?. As neuroscience findings are increasingly applied to social problems, in many cases raising ethical questions, it is important to enhance the neuroscience literacy of the public, so that they can be informed participants in the public dialogue (Illes & Bird, 2006).

This is especially true because public reporting of neuroscience findings often emphasize their potential benefits rather than their limitations. Racine et al. (2010) examined the public media's reporting on neurotechnology in the US and UK, finding that it featured mostly clinical and non-clinical benefits (79%). In contrast, scientific, medical, ethical, legal and social concerns were only discussed in 34% of articles. These findings suggest that media reporting is too optimistic about the potential of the application of neuroscience findings to other fields. Given the public's general lack of knowledge about basic brain function and the interpretation of neuroimaging data, the reporting of neuroscience findings without critical evaluation is potentially problematic.

Making matters worse is the seductive power of neuroimaging findings as a privileged form of scientific evidence. People find popular reporting more persuasive when it is accompanied by brain images and incorporates neuroscience language than when it makes no reference to the brain (McCabe & Castel, 2008; Weisberg et al., 2008). Given (1) the tendency to focus on potential benefits rather than critical limitations and (2) the general lack of understanding of the multi-step process of producing neuroimages, there is great potential for the potential misapplication of neuroscience findings to the other fields. The gap between the public's enthusiasm for neuroscience findings and its ability to critically evaluate them suggests the need for greater instruction on basic brain function and neuroimaging methodologies.

2.2 Educator interest in neuroscience findings

Educators' interests in neuroscience findings are understandable given that the brain underwrites thinking and learning. Neuroscience findings provide scientific evidence that *potentially* supports educators' instructional strategies (Hall, 2005; Goswami, 2006). The relation between education and neuroscience has a long – and often dubious – history. For example, early on, the shape and size of brains were considered as predictors of people's cognitive capabilities (Rushton & Ankney, 1996).

Howard-Jones et al. (2007) found that UK educators were interested in neuroscience research on developmental disorders, memory, gender differences, sensitive/critical periods, cognitive development, intelligences, and creativity. The importance of the plasticity of the brain responding to early educational interventions through enriched environmental stimuli were also of great interest. However, their interests sometimes mislead them in the interpretation of neuroscience findings.

For example, "brain-based learning" is an attempt to rationalize educational methods by presenting relevant brain function discoveries about teaching and learning (Caine & Caine, 1994; Davis, 2004). Jensen (2008) promoted brain-based learning as the "engagement of strategies based on principles derived from an understanding of the brain". This notion seems to be based on science, and indeed proponents of brain-based learning argue that brain research results lead to the development of practices for the classroom (Byrnes, 2001; Jensen, 2008; Zull, 2002). However, their arguments often over-simplify and distort original neuroscience research in the process of translating it to the educational context (Willingham, 2006). As a result, the promotion of left-right brain instruction, learning styles, and multiple intelligences are closer to pseudoscience than to science (Geake, 2008).

Educators' increasing interest in neuroscience findings has resulted in the establishment of a number of institutional structures:

- AERA's (American Education Research Association) Special Interest Group – *Brain, Neuroscience, and Education*,
- EARLI's (European Association for Research on Learning and Instruction) Special Interest Group - *Neuroscience and Education*,
- journals such as "*Mind, Brain, and Education*" and "*Trends in Neuroscience and Education*",
- university degree and certification programs such as:
    - "*Educational Neuroscience*" at Vanderbilt University in the Ph. D. degree program,
    - "*Mind, Brain, and Education*" at Harvard University and the University of Texas-Arlington in the master's degree program, and at Dartmouth University in the undergraduate program,
    - "*Neuroscience and education*" at Columbia University in the master's degree program,
    - "*Mind, Brain, and Teaching*" at Johns Hopkins University in the certificate program.
- other university and institute programs and funding such as:
    - "*BrainU*" at the University of Minnesota,

- "*Project NEURON*" at the University of Illinois,
- Dana Foundation's "*Brain awareness program*",
- *Using insight from neuroscience to improve education* (£6 million) funding from the Wellcome Trust and Education Endowment Foundation in the UK.

These efforts aside, there is still a need to guide educators' interest in the brain and to train them to understand neuroscience findings and apply them appropriately to educational practice, in contrast to the pseudoscience that is being peddled to them.

2.3 Why educators must know about neuroscience

There are number of reasons why educators must know more about brain function. Perhaps the most important reason is negative: As reviewed above, neuroscience findings are being increasingly applied to justify particular solutions to social, political, and economic problems. They are also being used to justify particular instructional approaches and programs. Neuroscience research on the underlying causes of learning disabilities is used to advocate for some remediation programs over others. Educational policy makers increasingly justify their policies by citing evidence from neuroscience research (see for example Brain Waves Module, 2011; Leadsom et al., 2013; NASDSE, 2011; NCATE, 2010). It is important that educators and educational policy makers understand neuroscience findings and methodologies well enough to critically evaluate the justifications for these applications.

In the remainder of this section, we review three additional positive reasons why educators must know more about brain function.

First, neuroscience research provides a new view on cognitive development. The brain is not a static organ, but rather changes continuously over the lifespan. Casey, Giedd, and Thomas (2000) identified three main features of structural brain development: (1) less changes in cerebral volume after five years, (2) significant decreases in gray matter after twelve years, and (3) continued changes in white matter from childhood to adulthood. Moreover, the emerging view of brain development both complements and extends influential view of cognitive development emanating from psychology, which have proven useful to educators in the past. For example, Casey et al. (2005) examined the developmental trajectory of the synaptic density of different areas of the cerebral cortex. Synaptic density peaked first in sensorimotor cortex, then in parietal and temporal association cortex, and finally in prefrontal cortex. This order roughly matches the four stages of Piaget' theory of cognitive development. The neuroscience view provides a more detailed and nuanced view of cognitive development. For example, the development of prefrontal cortex is accompanied by *decreasing* white-matter density, the product of increasing efficiency through the mechanisms of synaptic pruning and myelination (Casey, Galvan, & Haree, 2005). These brain mechanisms are not solely driven by maturation, but rather are sculpted by experience and environmental stimuli (Greenough, Black, & Wallace, 1987; Noble et al., 2012).

Second, neuroscience research is clarifying the causes of learning disabilities. This is part of the larger program of identifying *biomarkers* of learning disabilities

(Goswami, 2008). This includes dyscalculia (i.e., difficulty in processing numbers); for a review, see Butterworth, Varma, and Laurillard (2011). This also includes Attention Deficit Hyperactivity Disorders (ADHD; difficulty in regulating attention); for a review, see Fassbender and Schweitzer (2006). Perhaps most notably, this includes dyslexia, a point we develop in some detail here. Dyslexia refers to impaired reading acquisition and poor phonological awareness in the presence of normal intelligence and adequate educational resource. About 5 to 17 percent of children in classroom have the symptoms of dyslexia. Neuroscience research is helping illuminate the biological basis of dyslexia. Studies have found that children with dyslexia show reduced activation in the left temporoparietal cortex when processing words (Gabrieli, 2009). Logitudinal studies are proving the effectiveness of early ERP responses for diagnosing later difficulty in reading (Guttorm et al., 2005). This is particularly important because behavioral measures are often unsuitable for measuring the language processing of very young children. However, measuring different ERP responses to speech sounds is being used to help identify infants at risk for the future development of reading disorders. Finally, neuroscience is helping understand why some remediation programs work. A typical finding is that behaviorally successful interventions are accompanied by increased activation in formerly underactivated areas associated with remediated language skills (Shaywitz et al., 2004; Temple et al., 2003). More generally, knowing about the brain helps educators to provide children with dyslexia a proper remedy and instructional strategies to remediate their difficulty in reading.

Third, neuroscience research is informing learning in the disciplines. Early cognitive neuroscience studies focused on identifying the neural correlates of basic cognitive abilities such as attention, memory, and executive function (Posner & Peterson, 1990; Squire, 2004; Collette et al., 2005). More recent research is revealing how people understand language (Hruby & Goswami, 2011; Moss et al., 2011) and science (Crone et al., 2009; Fugelsang & Dunbar, 2009), and this knowledge can inform the design of instructional activities for teaching these subjects. We focus here on the case of mathematics, specifically numerical and arithmetic processing, and their development. Dehaene et al. (2003) identified three parietal circuits for numerical processing: the horizontal segment of the intraparietal sulcus (HIPS) is associated with magnitude processing of numbers, the left angular gyrus (AG) with verbal processing of numbers, and the bilateral posterior superior parietal lobe with visual-spatial and attentional orienting. With respect to arithmetic processing, and of skills from effortful step-by-step calculation to simple retrieval of answers is associated with a shift in activation from fronto-parietal networks to distinct parietal circuits. This is true over development more broadly (Rivera et al., 2005). This is also true following specific instructional interventions. For example, repeated or trained problems sets deactivated fronto-parietal areas and activated more the left AG associated with retrieval of arithmetic facts such as memorization of multiplication table (Delazer et al., 2003).

2.4 Efforts in bridging education and neuroscience

There is a long history of attempts to bridge between education and neuroscience. The neurologist Donaldson (1895) and the educator Halleck (1896) approached this goal through topics such as gender, neuroplasticity, critical periods, nature and nurture, and sleep/awake rhythms (Théodoridou & Triarhou, 2009). A particularly important contribution was Thorndike's (1926) proposal that the association between stimulus and response is represented in a neural bond. In the ensuing years, neuroscientists, cognitive scientists, psychologists, and educators continued to search for fruitful relationships between education and neuroscience in reports such as '*Education and the Brain*' and '*Neural Mechanisms of Learning and Memory*' (Chall & Mirsky, 1978; Rosenzweig & Bennett, 1976).

The remarkable recent progress in fields such as educational science, cognitive science, and neuroscience, and the development of non-invasive neuroimaging methodologies, have opened a new chapter in the application of neuroscience findings to education (Berninger & Corina, 1998; Mayer, 1998; Schunk, 1998; Sylwester & Cho, 1992). Different researchers name this emerging interdisciplinary field differently. "Educational neuroscience" is often used when the emphasis is on timing in education, cognitive mechanisms, developmental sequences in learning contents, and appropriate teaching methods (Petitto & Dunbar, 2004). "Mind, brain, and education" is often used when the emphasis is on collaborative research between educators and neuroscientists on human learning and development (Fischer et al., 2007). But these distinctions are blurry, these definitions contentious. For example, Szűcs and Goswami (2007) defined educational neuroscience as integrating neuroscience and behavioral methods for the study of mental representation. This definition echoes Bruer's (1997) influential argument that neuroscience results are incompatible with education results, but that this incompatibility can be resolved if cognitive psychology is allowed to play a mediating role.

A fundamental tension is whether neuroscience or education should take the leading role. Too often in the past, the lead has been handed to – or presumed by – neuroscience. For example, although Ansari and Coch (2006) proposed a bidirectional approach between education and cognitive neuroscience, most of their examples and results were drawn from the latter field. This imbalance heightens the barriers of entry for educators interested in learning about neuroscience and applying its findings to problems in education.

The problem of constructing a fully bidirectional bridge between education and neuroscience, and of truly reciprocal exchange and collaboration between both groups of researchers, remains. The current study addresses this problem in a novel way. It investigates whether the introductory educational psychology course that is a core part of most pre-service teacher training programs can help bridge between the disciplines, increasing teachers' neuroscience literacy and decreasing their beliefs in neuromyths. This intervention is clearly on the educator's turf restoring some balance to educational neuroscience.

2.5 Neuroscience literacy

Neuroscience literacy refers to the informed layperson's understandings of neuroscience findings. Neuroscience literacy has been studied less than neuromyths, which we consider in the next section. We ground our definition in *science literacy* more generally, which is defined by three components: scientific concepts, processes, and situations (OECD, 2003). Scientific concepts concern knowledge about basic terminology, laws, and theories of scientific phenomena. Scientific processes concern accurate evaluation and interpretation of scientific evidence. Scientific situations concern the use of scientific knowledge to solve everyday, real-life problems.

This definition of science literacy is present to varying degrees in prior definitions of neuroscience literacy. Zardetto-Smith et al. (2003) defined neuroscience literacy as knowledge and understanding of concepts and process in neuroscience relevant to the health of the brain, and their interactions with environment. Labriole (2010) defined neuroscience literacy as understanding progress in neuroscience research and making decisions about health, drug use, and social issues.

We define neuroscience literacy as the ability to know the basic terminology, structures, and functions of the brain (i.e., neuroscience concepts); to understand how neuroscientists study the brain and produce neuroscience data (i.e., neuroscience processes); and to apply neuroscience findings to optimize brain function and development to address authentic real-world problems (i.e., neuroscience situations).

Prior studies have shown that educators have low neuroscience literacy, for example as measured by difficulty in interpreting neuroscience findings (Howard-Jones et al., 2009; OECD, 2002). This might reflect gaps in teacher training programs, which typically do not cover the terminology and methods of neuroscience (i.e., neuroscience concepts) nor the complex technical and statistical assumptions underlying dominant methodologies (i.e., neuroscience processes). These gaps prevent educators from understanding and analyzing the relation between neural activities on one hand and cognitive, emotional, and physical processes on the other during learning and instruction (i.e., neuroscience situations).

The lack of neuroscience literacy is particularly perilous because McCabe and Castel (2007) demonstrated that laypeople overweight the importance of brain images when evaluating scientific evidence. The implication is that educators who better understand neuroscience methods are less likely to misinterpret neuroscience findings. In fact, understanding concepts such as blood oxygenation, neural activity, localization, reductionism, reverse inference, and statistical inference might help educators to see the limitations of neuroscience findings – and to *not* overweight them (Farah, 2014).

To summarize, it is important to increase the neuroscience literacy of educators to make them more discerning consumers of the neuroscience literature. This will help them understand the implications and limitations of neuroscience findings that are used to argue, often incorrectly, for some instructional approaches over others. Their neuroscience literacy might be increased through pre-service teacher training or in-service teacher training. For example, Ansari and Coch (2006) advocated including neuroscience content in teacher training courses, to ensure that teachers are better-equipped to critically evaluate instructional approaches that purport to be “brain based”.

We follow this suggestion below, in evaluating whether the core educational psychology course in many teacher training programs is an effective target for increasing neuroscience literacy. Another pathway for increasing neuroscience literacy is accessing public media sources such as books, magazine and newspaper articles on neuroscience. The current study also investigates whether this behavior is associated with increased neuroscience literacy.

2.6 Neuromyths

A problem that has plagued attempts to bridge neuroscience and education has been the presence of neuromyths, which are widely believed – but incorrect – statements about brain function. They are a consequence of educators' eagerness to translate what they learn about the mind and brain from the media into their teaching strategies, and of educational policy makers wanting to borrow neuroscience findings to argue for the effectiveness of their decisions (Caine & Caine, 2011; OECD, 2002; Puckett, Marshall, & Davis, 1999). This application of neuroscience findings without careful consideration has resulted in widespread misunderstandings and over-interpretations of neuroscience findings. This problem has been exacerbated by businesses eager to capitalize on educators' interest in neuroscience (Fischer, Goswami, & Geake, 2010).

The OECD's Brain and Learning project (2002) identified a number of prevalent neuromyths such as the (over)importance of hemisphere dominance and an overemphasis on early development (i.e., “enriched” environments and “critical” periods).

With respect to hemisphere dominance, educators often believe that the left hemisphere is logical, associated with language and analysis, whereas the right hemisphere is intuitive, associated with spatial patterns and creativity. This caricatured understanding of brain lateralization has led to the development of left- vs. right-brain based curricula. Left-hemisphere-oriented lesson focuses on reading and writing, whereas right-hemisphere-oriented lesson emphasizes visual representations (Geake, 2008). These unbalanced lessons actually have a negative effect on integrating across analytic and spatial learning thinking (Alferink & Farmer-Dougan, 2010), and on the integration of the two hemispheres more generally (Hellige, 2000).

This neuromyth likely has its origins in seminal neuroscience research comparing split-brain patients to normal, healthy participants (Hall, 2005). In these experiments, when patients touched an object with their right hand, they could easily name the object, but not when they touched it with their left hand (Gazzaniga & Sperry, 1967). This is a foundational piece of evidence for the left-lateralization of language. However, over-generalizing this result to typical individuals is not valid, and in fact studies of aphasia patients and more contemporary neuroimaging studies have revealed that the language network spans both hemispheres (Just & Varma, 2007).

With respect to overemphasis of early development, a common neuromyth is the belief that early educational interventions using "enriched environments" can "save" and even "create" more synapses, increasing learning capability. This coupled with the belief that once children enter elementary school, it is already too late to benefit from "enriched environments". This misunderstanding of synaptogenesis and a belief in the older notion of “critical periods” (versus the more modern notion of “sensitive” periods) has led to an overemphasis on interventions in the earliest years of life (Bruer, 1997).

There is little empirical research results to prove the relationship between synaptic densities and learning capacity in human subjects (Goswami, 2004). Even though previous neuroscience findings proved the importance of complex environments in animals (Diamond et al., 1987; Wiesel & Hubel, 1963), it is unclear whether the results of these animal experiments extend to humans. Moreover, different parts of the brain undergo synaptogenesis at different points during development, including after children have entered school (Gogtay et al., 2004). Finally, the notion of “critical period” comes from language acquisition, specifically phonological awareness (Kuhl, 2004). It is unclear whether other aspects of language development (i.e., orthographic, morphological, lexical, syntactic, semantic, discourse, pragmatic) are also bound by “critical periods” (Kluger & Park, 2001).

Geake (2008) identified two classes of neuromyths appearing in popular ‘brain-based’ education programs. Some were of the type “more is better”: 10% usage of brain, multiple intelligences, and the effects of coordination exercise on the integration of brain function (i.e., Brain Gym). Others were of the type “more specific is better”: left-and right-brained thinking and VAK (visual, auditory and kinesthetic) learning styles. These two classes of neuromyths reflect the ways in which educators simplify neuroscience findings when applying them to educational practice.

To summarize, beliefs in neuromyths increases confusion about brain function and learning among educators, and ultimately wastes time, money, and effort (Sylvan &

Christodoulou, 2010). It is therefore important to dispel the neuromyths of educators and to make them more critical consumers of applications of neuroscience findings. The current study identifies pre-service teachers' neuromyths, and investigates whether they are reduced by taking an introductory educational psychology course that introduces relevant material such as the scientific method, theories and data on cognitive development, and so on.

2.7 Measuring neuroscience literacy and beliefs in neuromyths

There have been several prior attempts to measure neuroscience literacy and beliefs in neuromyths. Herculano-Houzel (2002) constructed a survey to measure the public's neuroscience literacy and belief in neuromyths in Brazil. Greater neuroscience literacy was associated with more schooling, with the scores of people with graduate degrees 30% higher than those of people with high school degrees. Greater neuroscience literacy was also associated with reading popular science magazines and newspapers. However, neuromyths were still widely prevalent. Even among people with college educations, 59% believed the neuromyth that "We use only 10% of the brain." People also had misconceptions about the relationship between emotion and reasoning, the analogy between the brain and computer, and the effect of physical exercise on brain activity.

These results were replicated in the United Kingdom, in a study by Howard-Jones et al. (2009) of graduate trainee teachers. Trainee teachers believed neuromyths about the usefulness of preferred learning styles, the relevance of hemispheric dominance for learning, the effectiveness of Brain Gym, and the effect of drinking water and taking Omega-3 supplements on learning. Perhaps not surprisingly, higher neuroscience literacy scores were associated with reduced beliefs in neuromyths.

Dekker et al. (2012) investigated the prevalence and predictors of neuromyths among teacher in the United Kingdom and Netherlands. Almost half of the teachers who took the survey believed in some neuromyths. More than 80% of teachers believed in preferred leaning styles, hemispheric dominance, and the benefits of coordination exercises on the integration of brain function. In addition, the pesky neuromyth about 10% usage of brain was believed by 48% of UK teachers and 46% of Netherland teachers. A natural prediction is that the more schooling and prior knowledge about the brain people have, the greater their neuroscience literacy and the less their beliefs in neuromyths. Somewhat surprisingly, this was *not* the case: possessing more prior knowledge about neuroscience did not reduce teachers' beliefs in neuromyths.

These studies are important for three reasons. First, they suggest that neuromyths are believed by the public in general and educators in particular. Critically, neuromyths are not specific to one country, but rather widespread across the multiple countries spanning multiple continents. Second, they demonstrate that, neuroscience literacy as well as belief in neuromyths, can be measured using survey questionnaires. Third, they provide evidence that the neuroscience literacy is (sometimes) positively associated with opportunities to learn about the brain from additional schooling and from public media. The current study builds upon all three of these developments. It investigates whether academic history – prior coursework in biology or neuroscience – is associated with increased neuroscience literacy and reduced beliefs in neuromyths. It also queries the independent sources from which educators learn about neuroscience findings.

2.8 Educators' views on the role of neuroscience in education

Educators are generally optimistic about the application of neuroscience findings for educational practice. However, there are differences across countries on the details of this application.

Pickering and Howard-Jones (2007) concluded that, for educators in the UK, understanding brain function is important for supporting the design and delivery of educational activities, especially for individuals with special needs, less important for deciding what to teach (i.e., curriculum content). This stands in contrast to the finding that Portuguese teachers mostly agree that understandings brain function is important for making decisions about curriculum content (Rato, Abreu, & Casto-Caldas, 2011).

Zambo and Zambo (2009) measured the opinions of pre-service teachers in the US about the relevance of brain research for education practice. They documented positive views about applying neuroscience findings to improve instruction and to inform educational practice. However, they also found concerns about misinterpreting neuroscience findings when applying them to educational practice and when using them to decide who will receive educational enrichment.

There have been no studies of Korean educators' perceptions of the relevance for neuroscience findings for educational practice. However, several conceptual analyses have been offered (e.g., Choi & Shin, 2014). For example, based on neuroscience research on attentional networks and plasticity, Cho (1994) suggested that utilizing a diversity of stimuli and instructional strategies is important for maintaining learners' attention, and therefore for enhancing learning and memory.

To summarize, educators in Europe, South and North America, and Korea are optimistic about the application of neuroscience to education, but differ on which applications of neuroscience findings to educational problems are likely to be most productive. The current research investigates the points of agreement and disagreement in two countries, the US and Korea.

3 The Current Study

The primary purpose of the current study was to investigate the neuroscience literacy and beliefs in neuromyths of pre-service teachers before and after taking an educational psychology class.

Our primary hypothesis was that although educational psychology courses do not directly present neuroscience research, they present psychological theories and data relevant to the interpretation of neuroscience findings. They also emphasize normative scientific reasoning about topics in psychological and social science. Finally, they introduce the notion that data are not “facts”, but rather evidence, and that to properly evaluate data, an understanding of statistical concepts (e.g., noise) is necessary. Therefore, we hypothesized that taking an introductory educational psychology will enhance pre-service teachers’ neuroscience literacy and reduce their beliefs in neuromyths. Neuroscience literacy and beliefs in neuromyths were measured using a survey that builds upon the content of prior surveys.

We focused on pre-service teachers majoring in elementary education because generally they have fewer opportunities to learn about science in general and neuroscience in particularly compared to middle and high school teachers, who can choose to specialize in science or mathematics education. We hypothesized that they would show relatively low levels of neuroscience literacy and relatively prevalent beliefs in neuromyths before taking an introductory educational psychology course, and as a result would benefit more from the theoretical, empirical, methodological, and philosophical content of the course. We collected two samples, one of US pre-service teachers and one of Korean pre-service teachers, to investigate cross-cultural differences.

More precisely, the current study investigated four research questions: (1) Is neuroscience literacy enhanced when pre-service teachers take an introductory educational psychology course, and are these changes different for US and Korean pre-service teachers? (2) Is belief in neuromyths reduced when pre-service teachers take an introductory educational psychology course, and are these changes different for US and Korean pre-service teachers? (3) What *a priori* factors – academic history and information sources for learning about neuroscience research – impact neuroscience literacy and beliefs in neuromyths in US and Korean pre-service teachers? (4) What are the attitudes about applying neuroscience findings to educational practice are they different for US and Korean pre-service teachers?

4 Method

4.1 Participants

The US participants were recruited from pre-service teachers enrolled in an introductory educational psychology course in the Fall 2013 or Spring 2014 semesters at the University of Minnesota. Participants who voluntarily completed survey questionnaire twice – at the beginning and at the end of the course – were included in the final sample. The final sample included 70 (63 females, 7 males) participants. Most (N = 57, 81.4%) were elementary education majors; the other majors included music, special education, and agricultural education. Participants' average age was 21.47 years (SD = 4.01).

The Korean participants were recruited from pre-service teachers enrolled in an introductory educational psychology course in the Spring 2014 semester at Seoul National University of Education. Again, the final sample only included participants who completed the survey twice, once at the beginning of the course and once at the end. All participants were pre-service teachers who majored in elementary education. The final sample size was N = 50 (35 females, 15 males). Participants' average age was 20.86 years (SD = 2.33).

4.2 Materials

4.2.1 Neuroscience knowledge survey

We developed a survey questionnaire to measure pre-service teachers' neuroscience literacy and belief in neuromyths, as well as to collect information about their background and attitudes about applying neuroscience findings to educational practice.

The first part measured neuroscience literacy and belief in neuromyths. It consisted of 60 items, 28 correct and 32 incorrect; see the Appendix A. Correct and incorrect statements were randomly ordered. Participants judged each statement as correct ("Yes"), incorrect ("No"), or "I don't know". The number of correct answers across all items constituted their neuroscience literacy score (60 items; Cronbach's alpha = .760 for the pre-test and .754 for the post-test in the US and Cronbach's alpha = .836 for the pre-test and .7113 for the post-test in the Korea). A subset of neuromyth items were defined operationally as items that were answered incorrectly (i.e. "No" response to correct statement, "Yes" response to incorrect statements) more than 50% of the time at pre-test. The number of incorrect answers across the neuromyth items constituted their belief in neuromyths score.

The survey was developed by first collecting the basic knowledge of brain function and correct / incorrect statements about the brain from previous studies of neuroscience literacy and belief in neuromyths (Beck, 2010; Dekker et al., 2012; Herculano-Houzel, 2002; Howard-Jones, 2007; Marcus, 2012; Penttila, 2010; Schultz, 2009; Simons & Chabris 2011; Stix, 2013; Tokuhama-Espinosa, 2009; Wardlaw et al., 2011; C. Loftus & J. M. Dubinsky, personal communication, 2009). These 123 items were reduced to a more manageable set of 60 items by removing those that were redundant, debate-able, or of little relevance to educational practice. Most of the surviving items came from the Dekker et al. (2012) and Herculano-Houzel's (2002) studies. We also wrote new items about recent neuroscience research on topics such as synaptogenesis, myelination, glia cell, emotional processing (i.e., affective neuroscience), the use of cognitive enhancers, and neuroimaging methodologies. The accuracy of items was determined by faculty members in the departments of elementary education, science education, educational psychology, and neuroscience at the University of Minnesota and Seoul National University of Education.

A novel feature of the new survey was that items were organized into six sections of interest. The *I. General knowledge* section contained 14 items (3 correct and 11 incorrect) about intelligence, memory, dreaming, bilingual education, and the "use" of our brain. The *II. Localization of brain function* section contained 8 items (3 correct and 5 incorrect) about the lateralization and plasticity of brain function. The *III. Brain development* section contained 10 items (7 correct and 3 incorrect) about the brain development of young children and adolescents. The *IV. Brain structure* contained 12 items (7 correct and 5 incorrect) about basic anatomy of brain, synaptogenesis, and communication. The *V. Neuroimaging* section contained 6 items (3 correct and 3 incorrect) about neuroimaging methodologies and the interpretations of neuroimaging data. Finally the *VI. Applying neuroscience results* section contained 10 items (5 correct and 5 incorrect) related to the application of neuroscience findings to daily life (brain diseases and the effects of foods and drugs).

The survey included items collecting background information about the age, gender, and academic history (i.e., number of biology and neuroscience courses taken) of participants. It also included items querying participants' main information sources about neuroscience research. Finally, it included items measuring participants' attitudes about applying neuroscience findings to educational practice. The final set of attitude items was drawn from surveys developed by Pickering and Howard-Jones (2007) and Farah (2012).

The survey was created in English and translated into Korean for the Korean participants. The accuracy of translation was confirmed by double-blind peer review.

4.2.2 Introductory educational psychology course

The purpose of the introductory educational psychology course in both countries was to present scientific theories about learning and educational practice relevant for pre-service teachers. The topics included cognitive, social, and emotional development; individual differences and learning disabilities; attention, cognition, and memory; intelligence; motivation; assessment; and instruction and classroom management. The materials included textbook readings, lectures, and conventional assignments and exams. Of particular importance, the courses were relatively traditional, and there was no direct information about connecting education and neuroscience.

The textbook for the US course was Santrock's (2010) *Educational Psychology,* (*5th edition*). The material covered in given in Appendix B. The neuroscience-relevant content included one section describing the development of neurons and brain regions, brain development in childhood and adolescence, lateralization, plasticity, and the relation between brain development and children's cognitive and language development. Critically, those sections included no content directly relevant for distinguishing correct and incorrect items in the neuroscience knowledge survey. The course instructor and teaching assistant were graduate students specialized in educational psychology.

The textbook for the Korean course was a translation of Eggen and Kauchak's (2009) *Educational Psychology: Windows on classroom* (*9th edition*). The material covered is given in Appendix B. Neuroscience-relevant content included sections describing the basic structure of neurons, the function of the cerebral cortex, myelination, and "brain-based learning". There were also brief explanations about misinterpretations about the left and right hemispheres and about critical periods that overlapped with some of the items in neuroscience knowledge survey. The course instructor was a professor trained in education and cognitive psychology whose research interests include bridging education and the study of the brain.

Overall, the introductory educational psychology courses in the US and Korea were comparable, with the exception that the textbook used in the Korean course explicitly addressed neuromyths concerning hemispheric differences and critical periods.

4.3 Procedure

At the pre-test, conducted at the beginning of the semester, the consent form explained that the purpose of this study is investigating educators' understanding of neuroscience research related to learning and educational practice. The terms "neuroscience literacy" and "neuromyths" were not used. Participants provided informed consent. They then completed the neuroscience knowledge survey. Participants were not informed that there would be post-test at then end of semester, to ensure that they did not engage in extra-curricular study of neuroscience.

The course instructors were not allowed to see the neuroscience knowledge survey during the semester, to ensure they did not tailor their instruction to the items.

At the post-test, conducted at the end of the semester, the survey was introduced as an assessment tool for evaluating the impact of taking an educational psychology course on improving educators' understanding of neuroscience relevant to educational practice. Again, the terms "neuroscience literacy" and "neuromyths" were not used. Participants complete the survey. The order of items within each section was randomized. The background information was only collected once, at pre-test, because it was assumed to be unchanged across the short time span of one semester. However, attitudes about applying neuroscience findings to educational practice were measured at both administrations, as these might have been affected by taking the introductory educational psychology course.

4.4 Data analysis and design

The data was analyzed using SPSS version 20.0 and jMetrik version 3.0. We examined the distributions of responses to each statement and calculated the percentage of correct responses separately for each section and for the overall survey. Item analysis was performed to calculate each statement's correct response rate (i.e., item difficulty). Independent *t*-tests were conducted to identify differences in neuroscience literacy and beliefs in neuromyths in the US and Korean samples.

To examine differences in the impact of taking an introductory educational psychology course on neuroscience literacy and beliefs in neuromyths, we conducted two-way ANOVAs with repeated measures *Pre-Test score* and *Post-Test score* and with between-subjects factor *Country*. We performed these analyses separately for each section of the neuroscience knowledge survey and for the overall survey.

To examine predictors of neuroscience literacy and beliefs in neuromyths, we analyzed the relation between performance on the neuroscience knowledge survey and each of academic history, information sources for learning about neuroscience findings, and attitudes about applying neuroscience findings to educational practice using *t*-tests, chi-square tests of independence, *z*-tests, and correlations as appropriate.

5 Results

5.1 Neuroscience Literacy

The first research question is whether neuroscience literacy is enhanced when pre-service teachers take an introductory educational psychology course, and whether these changes are different for US versus Korean pre-service teachers. We analyzed overall neuroscience literacy scores at pre-test and post-test (within-subjects factor) in US and Korean pre-services teachers (between-subjects factor) in a two-way ANOVA. There was a main effect of time ($F(1,118) = 45.223$, $p < .001$, $\eta_p^2 = .277$). As predicted, taking an educational psychology course improved the overall neuroscience literacy score of pre-service teachers. There was also a main effect of country ($F(1,118) = 7.813$, $p = .006$, $\eta_p^2 = .062$), with US pre-service teachers having higher overall neuroscience literacy score than Korean pre-service teachers. Critically, there was a Time-by-Country interaction ($F(1,118) = 7.159$, $p = .008$, $\eta_p^2 = .057$) suggesting a closing of the gap between the US and Korean samples (see Figure 1).

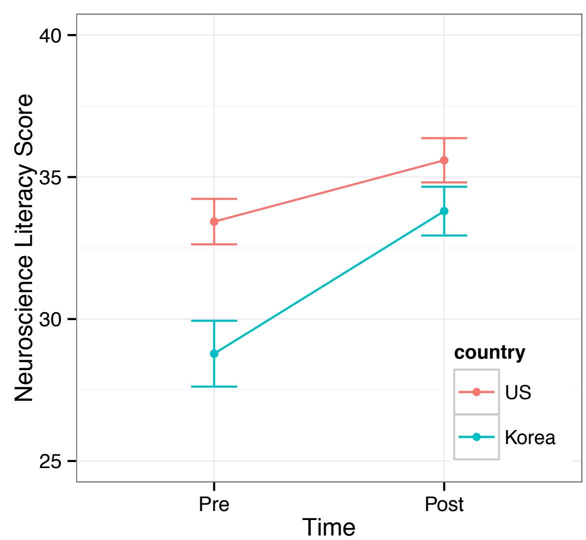

Figure 1. Neuroscience literacy score in US and Korean pre-service teachers.

Table 1.

Effect of taking an introductory educational psychology course on the neuroscience literacy of pre-service teachers in the US and Korea.

Section (number of items)	US		Korea		ME Time	ME Country	Time X Country
	Pre *M* (*SD*)	Post *M* (*SD*)	Pre *M* (*SD*)	Post *M* (*SD*)	p (η_p^2)	p (η_p^2)	p (η_p^2)
I. General knowledge (14)	8.20 (2.2)	8.80 (1.8)	7.38 (2.4)	8.02 (2.2)	.003 (.074)	.021 (.044)	*ns*
II. Localization of brain function (8)	4.56 (1.4)	4.27 (1.4)	3.54 (1.4)	4.14 (1.1)	*ns*	.008 (.058)	.001 (.091)
III. Brain development (10)	6.01 (1.5)	6.73 (1.5)	4.42 (2.2)	6.00 (1.6)	< .001 (.273)	< .001 (.143)	.013 (.051)
IV. Brain structure (12)	5.84 (2.1)	6.10 (2.0)	5.42 (2.0)	6.04 (1.8)	.014 (.051)	*ns*	*ns*
V. Neuroimaging (6)	2.56 (1.6)	3.07 (1.7)	2.48 (1.6)	3.46 (1.4)	< .001 (.150)	*ns*	*ns*
VI. Applying neuroscience results (10)	6.26 (1.4)	6.61 (1.6)	5.58 (1.6)	6.14 (1.8)	.013 (.051)	.014 (.050)	*ns*
Total (60)	33.43 (6.7)	35.59 (6.4)	28.78 (8.2)	33.80 (6.0)	< .001 (.277)	.006 (.062)	.008 (.057)

To better understanding these findings for overall neuroscience literacy scores, we conducted separate two-way ANOVAs for the six section scores (see Table 1). The main effect of Time, with higher scores after taking an introductory educational psychology course, was present for five of six sections ($F(1,118) > 6.287$, $p < .014$, $\eta_p^2 > .051$), with the largest effect on *III. Brain development* ($\eta_p^2 = .273$). The main effect of Country, with high scores for the US versus Korean pre-service teachers, was present for four of the six sections ($F(1,118) > 5.445$, $p < .022$, $\eta_p^2 > .044$). Interestingly, the largest effect size was again observed on *III. Brain development* ($\eta_p^2 = .143$). Finally, the Time-by-Country interaction was present in two sections, *II. Localization of brain function* and *III. Brain development* ($F(1, 118) > 6.31$, $p < .014$, $\eta_p^2 > .09$). In other words, these are the two sections on which Korean pre-service teachers were able to close the neuroscience literacy gap with US pre-service teachers.

5.2 Beliefs in Neuromyths

The second research question is whether beliefs in neuromyths are reduced when pre-service teachers take an introductory educational psychology course, and whether these changes are different for US versus Korean pre-service teachers. To identify neuromyths, we examined each item's distribution of response choices (see Appendices C and D). We operationally defined items that were answered incorrectly (i.e. "No" response to correct statement, "Yes" response to incorrect statements) more than 50% of the time at pre-test as neuromyths. There were 11 such items, all of which were incorrect statements (see Table 2). Four neuromyth items were believed by over 50% of US pre-service teachers and Korean pre-service teachers at pre-test. By contrast, seven neuromyth items were believed by over 50% of only one of the groups. US pre-service teachers were too literal in their belief in the computer metaphor for brain function (item I-13) and underestimated the effect of emotion (IV-10). In contrast, Korean pre-service teachers had stronger beliefs about the absoluteness of critical periods (III-9), the positive cognitive effects of physical exercise (IV-3), and lateralization of brain function (II-4, II-7). They also overestimated the influence of foods or drugs on brain function (VI-6).

Table 2.

Neuromyths believed by 50% or more of US or Korean pre-service teachers at pre-test or post-test.

Neuromyth	US		Korea	
	Pre (%)	Post (%)	Pre (%)	Post (%)
I-4. *Blind people have better hearing.*	61	57	80	78
I-13. *Memory is stored in the brain much like as in a computer. That is, each memory is encoded in a tiny piece of the brain.*	61	67	36	54
II-4. *Right-hemisphere learners are more creative than left-hemisphere learners.*	40	40	64	62
II-6. *Brief co-ordination exercises can improve integration of left and right hemispheric brain function.*	63	67	70	86
II-7. *The left side of the brain deals with rational thinking and the right side is emotional processing.*	40	48	82	80
III-6. *Environments that provide rich stimuli improve the brain function of pre-school children.*	83	91	88	98
III-9. *There are critical periods in childhood after which certain abilities can no longer develop and certain skills can no longer be learned.*	43	50	88	88
IV-3. *The volume of blood in the brain increases with physical effort.*	54	47	74	86
IV-10. *Emotional brain processes interrupt cognitive brain processes such as thinking and reasoning.*	61	70	26	24
VI-4. *Children are less attentive after consuming sugary drinks and/or snacks.*	66	64	64	54
VI-6. *It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement.*	33	34	60	46

Note: The numbers of percentage indicate the proportion of incorrect "Yes" responses to each neuromyths.

To analyze beliefs about neuromyths more systematically, we computed a neuromyths score for each participant, the number of neuromyths items incorrectly answered (i.e., "Yes" response to incorrect statements). Note that higher scores indicate beliefs in more neuromyths (i.e., worse performance) and lower scores indicate beliefs in fewer neuromyths (i.e., better performance). We conducted a two-way repeated ANOVA with within-subject factor Time and between-subjects factor Country. Contrary to our predictions, there was no main effect of time (p = .104). Thus, beliefs in neuromyths did *not* decrease after taking an introductory educational psychology course. There was a marginal main effect of Country ($F(1,118) = 13.078$, $p < .001$, $\eta_p^2 = .100$), with Korean pre-service teachers believed more neuromyths items ($M = 7.33$, $SD = 2.08$) than their US counterparts ($M = 6.21$, $SD = 2.11$). Finally, there was no Time-by-Country interaction (p = .758), indicating that taking an introductory educational psychology course did *not* close the neuromyth gap between Korean and US pre-service teachers (see Figure 2).

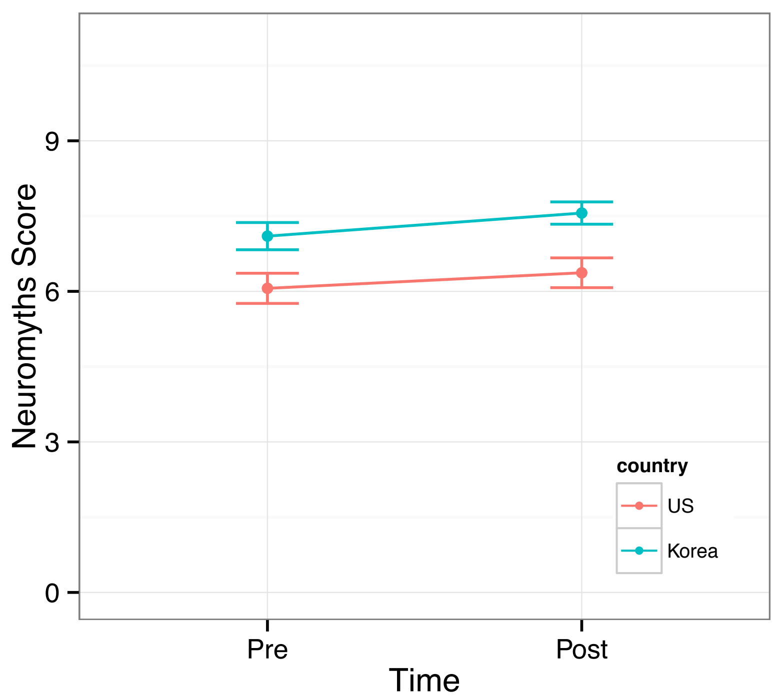

Figure 2. Neuromyths score in US and Korean pre-service teachers.

5.3 Background factors

The third research question addressed the impact of prior coursework in the biological sciences and the information sources participants consulted to learn about new neuroscience findings.

We investigated whether prior biology or neuroscience coursework was associated with increased neuroscience literacy or decreased beliefs in neuromyths. In the US sample, 83% of participants (N =58) had taken one or more biology classes and 20% of participants (N = 14) had taken one or more neuroscience classes. In the Korean sample, only 14% of participants (N = 7) had taken one or more biology classes and none had taken one or more neuroscience classes. This is likely because in Korea, the undergraduate curriculum in teachers colleges focuses on training elementary school teachers, and these participants have little or no opportunity to take courses in the biological sciences, even as electives.

We first investigated whether prior coursework increased neuroscience literacy. Contrary to our prediction, this was not the case (see Table 3). For US pre-service teachers, those who had taken prior biology courses had comparable neuroscience literacy scores to those who had not, both at pre-test and at post-test (ps > .569). The same was true for Korean pre-service teachers (ps > .409). For US pre-service teachers, those who had taken prior neuroscience courses had comparable neuroscience literacy scores to those who had not, both at pre-test and at post-test (ps > .400). A parallel analysis could not be performed for Korean pre-service teachers because none had taken prior neuroscience courses. We then investigated whether prior coursework reduced

Table 3.

Effect of taking biology or neuroscience courses on the overall neuroscience literacy score at each time point of each group.

		US				Korea			
		1+ courses	no courses	*t* (68)	*p*	1+ courses	no courses	*t* (48)	*p*
Pre	Biology	33.64 (7.1)	32.42 (4.5)	.573	*ns*	27.71 (8.7)	28.95 (8.3)	-.366	*ns*
	Neuroscience	32.07 (8.8)	33.77 (6.1)	-.846	*ns*				
Post	Biology	35.71 (6.6)	35.00 (5.8)	.344	*ns*	35.57 (5.4)	33.51 (6.2)	.833	*ns*
	Neuroscience	36.00 (6.8)	35.48 (6.4)	.267	*ns*				

Table 4.

Effect of taking biology or neuroscience courses on the overall score in neuromyths items at each time point of each group.

		US				Korea			
		1+ courses	no courses	*t* (68)	*p*	1+ courses	no courses	*t* *(48)*	*p*
Pre	Biology	6.08 (1.6)	6.05 (2.2)	.047	*ns*	8.14 (1.5)	6.93 (2.3)	1.321	*ns*
	Neuroscience	6.79 (2.5)	5.88 (2.0)	1.445	.020				
Post	Biology	6.36 (2.0)	6.42 (2.4)	-0.81	*ns*	8.71 (1.1)	7.37 (1.9)	1.807	*ns*
	Neuroscience	6.07 (2.1)	6.45 (2.1)	-.595	*ns*				

beliefs in neuromyths. Again, contrary to our prediction, this was not the case (*p*s > .077) (see Table 4). That knowledge prior coursework in the biological sciences did not impact neuroscience literacy or beliefs in neuromyths is a surprising finding that we return to below.

We next investigated whether US and Korean pre-service teachers consulted different information sources to learn about recent neuroscience findings. The results are shown in Table 5. The main information sources consulted by both groups were books and public media. The proportion of information sources differed by country, χ^2 (5, N = 203) = 18.597, p = .002). The major difference was that books were a more important information source for US pre-service teachers than for Korean pre-service teachers (z = 2.508, p = .012), whereas public media were a more important information source for Korean pre-service teachers than for US pre-service teachers (z = -2.034, p = .003).

Table 5.
Main information sources about neuroscience in US and Korean pre-service teachers.

	US		Korea		*z*	*p*
	N	%	*N*	%		
Books	55	39.01	13	20.97	2.508	.012
Public Media	29	20.57	25	40.32	-2.934	.003
Scientific magazine and journals	19	13.48	8	12.90	.111	*ns*
Pre-service training	15	10.64	1	1.61	2.198	.028
Commercial products	13	9.22	5	8.06	.267	*ns*
Others	10	7.09	10	16.13	-1.990	.047

Note: Each participant could indicate multiple information sources.

Considering the public media's tendency to oversimplify and inappropriately extrapolate neuroscience findings, the differential exposure to public media might explain some of the differences between the two groups (O'Connor, 2014).

Another noteworthy difference was that US pre-service teachers reported learning more about neuroscience findings through pre-service training than their Korean counterparts ($z = 2.198$, $p = .028$). Finally, further analysis of the "Other" category revealed that 6% of US pre-service teachers reported about neuroscience findings through prior psychology courses, whereas on 7% of Korean pre-service teachers had no opportunity to learn about neuroscience findings. These results reveal interesting differences in how US and Korean pre-service teachers previously learned about and continue (in their teacher training programs) to learn about neuroscience findings.

5.4 Attitudes about Applying Neuroscience Findings to Educational Practice

The fourth research question was whether US and Korean pre-service teachers differed in their attitudes about applying neuroscience findings to educational practice.

We first focused on *general* attitudes about applying neuroscience findings to support educational practice (see Table 6). Across three questions, US ($M = 4.18$, $SD = .87$) and Korean ($M = 4.08$, $SD = .57$) pre-service teachers had equally positive attitudes ($p = ns$). The only difference was that US pre-service teachers had more positive attitudes about applying neuroscience findings to improve the design and delivery of instruction, $t(118) = 2.209$, $p = .029$, $d = .399$. We also looked for an association between positive general attitudes about applying neuroscience findings to educational practice

Table 6.

General attitudes about applying neuroscience findings to support educational practice in US and Korean pre-service teachers.

	US *M* (*SD*)	Korea *M* (*SD*)	*t* (118)	*p*
A. Scientific research on the neuroscience of learning is interesting.	3.84 (.99)	4.02 (.82)	-1.038	*ns*
B. Knowledge of the psychology is important for the design and delivery of instruction.	4.36 (1.00)	4.24 (.69)	.757	*ns*
C. Knowledge of the brain is important for the design and delivery of instruction.	4.33 (.96)	4.00 (.67)	2.209	.029
Average	4.18 (.87)	4.08 (.57)	.680	*ns*

Note: 1 = Strongly disagree, 5= Strongly agree.

and neuroscience literacy (as measured at pre-test, before taking the introductory educational psychology course). In addition, there was a small positive association between average general attitude and overall neuroscience literacy in both the US ($r = .303$, $p = .011$) and Korean ($r = .271$, $p = .057$) pre-service teachers. A possible causal explanation for this correlation is that positive general attitudes lead pre-service teachers to pay greater attention to and learn more about new neuroscience research, which in turn increases their overall neuroscience literacy. Of course, future research employing stronger designs is required to evaluate this causal explanation.

We next evaluated *specific* attitudes about applications of neuroscience findings to solve particular educational problems (see Table 7). US ($M = 2.54$, $SD = .54$) and Korean ($M = 2.48$, $SD = .50$) pre-service teachers again had equally positive attitudes ($p =$

ns). The only difference was that Korean pre-service teachers had more positive attitudes about using neuroimaging to choose the right career, $t(118) = -4.455$, $p < .001$, $d = .831$. We also investigated whether there was a positive correlation between average specific attitudes and overall neuroscience literacy (as measured at pre-test), but found correlations that were not reliably different than zero for both the US and Korean pre-service teachers ($p > .631$).

Table 7.

Specific attitudes about applying neuroscience findings to solve particular educational problems in US and Korean pre-service teachers.

	US *M* (*SD*)	Korea *M* (*SD*)	*t* (118)	*p*
D. Neuroimaging can help students to choose the right career.	2.59 (1.06)	3.40 (.88)	-4.455	< .001
E. The use of cognitive enhancers (i.e., "smart pills") should be tightly controlled in healthy individuals.	3.60 (1.15)	3.58 (.70)	.109	*ns*
F. Screening infants using neuroimaging would give result in the undesirable "labeling" of children.	3.70 (.97)	3.88 (.74)	-1.113	*ns*
Average	2.54 (.54)	2.48 (.50)	.644	*ns*

Note: 1 = Strongly disagree, 5= Strongly agree. When calculating average attitudes in applying neuroscience findings to ethical issues, items (E) and (F) were reverse-coded. High scores indicate more optimistic views.

6 Discussion

Prior investigations have used survey questionnaires to measure educators' neuroscience literacy and beliefs in neuromyths. The current study is among the first to utilize an experimental design to evaluate whether an instructional intervention – taking an introductory educational psychology course – increases neuroscience literacy and decreases beliefs in neuromyths. It is also among the first to sample from pre-service teachers in two countries, the US and Korea, to investigate commonalities and differences in a global context.

To briefly summarize the findings, the introductory educational psychology course increased neuroscience literacy in five of six domains, with the largest improvement in knowledge of brain development. Furthermore, the course closed the neuroscience literacy gap, with the Korean pre-service teachers closer to their US counterparts at post-test. Surprisingly, the introductory educational psychology course did not reduce beliefs in neuromyths. Also surprising was the finding that prior coursework in the biological sciences did not increase neuroscience literacy or reduce beliefs in neuromyths. US and Korean pre-service teachers used different information sources to learn about neuroscience research, with the former making greater use of books and the latter greater use of public media. Finally, although US and Korean pre-service teachers had comparable attitudes about the general use and specific applications of neuroscience research to solve educational problems, there were differences. Most notably, US pre-service teachers were more favorable about using neuroscience findings to improve instruction, whereas Korean pre-service teachers were more favorable about using neuroimaging methods to help students make career choices.

Below, we consider more general implications of these findings, limitations of this research, and directions for future research.

6.1 Increasing neuroscience literacy

With respect to the first research question, taking an introductory educational psychology course enhanced pre-service teachers' neuroscience literacy, with the largest improvement in knowledge of brain development. Moreover, although US pre-service teachers had higher overall neuroscience literacy at pre-test, their Korean counterparts closed this gap at post-test, driven by improvements in their knowledge of the localization of brain function and brain development.

We can understand these improvements with reference to the notion of neuroscience literacy developed above, and knowing neuroscience concepts (i.e., basic terminology, structures, and functions of the brain), neuroscience processes (i.e., how neuroscientists study the brain and produce neuroscience data), and neuroscience situations (i.e., how to apply neuroscience findings to optimize brain function and to address real-world problems. With respect to neuroscience concepts, an introductory educational psychology course provided basic knowledge about the phenomena of cognitive development such as assimilation, accommodation, critical periods, and sensitive periods. It introduces terminology for describing the structure and function of the brain such as neurons, synapses, and cerebral cortex. With respect to neuroscience processes, the course provided instruction on assessment – the valid measurement and interpretation of student performance. This involves introducing basic methodological concepts such as the scientific method and the statistical analyses of noisy data. With respect to neuroscience situations, the course provided numerous examples of how psychological theories, developed originally to explain esoteric laboratory data, can be applied to improve instruction and assessment of student learning, identify and address learning disabilities, and illuminate how children learn content domains such as reading, mathematics, and science. To summarize, introductory educational psychology courses directly target the three components of neuroscience literacy.

A complementary explanation for the improvement in neuroscience literacy after taking an introduction to educational psychology course is the quality of the textbooks used: Santrock (2010) by the US pre-service teachers and Eggen and Kauchak (2009) by their Korean counterparts. Both argued for a close relation between brain development, cognitive development, and language development. Both pointed to myelination – enhancing the speed of information propagation in neurons – as an important mechanism in driving cognitive development. Both introduced synaptic density – an indicator of the extent of the connectivity of neurons – as an important mechanism of brain development that ultimately drives how much children can learn from experience during their own cognitive development.

There are diverse approaches to increasing the neuroscience literacy of teachers such as boot camp, certifications, and graduate school program for in-service teachers. The current findings identify pre-service teacher training programs as another mechanism for improving educators' neuroscience literacy. The positive results of the current study coupled with the openness of pre-service teachers to explanations – whether neuroscientific, psychological, or educational – of learning, instruction, assessment, and individual differences suggested that pre-service programs might be the best point at which to increase neuroscience literacy. Of course, further studies are required to evaluate this proposal, and even if their findings are supportive, the practical difficulties of introducing new neuroscience content into already overstuffed teacher training programs would remain (Dubinsky, Roehrig, & Varma, 2013).

6.2 Decreasing beliefs in neuromyths

With respect to the second research question, taking an introductory educational psychology course did *not* reduce beliefs in neuromyths. This was surprising. Prior studies have documented the existence of neuromyths about people using only 10% of their brains, left-and right-brain hemispheric dominance, the Mozart effect, and the effectiveness of Brain Gym-like exercises. We predicted that taking an introductory educational psychology course would dispel some of the neuromyths. This prediction was not supported. However, a closer examination of the data revealed that neuromyths may not be stable: some neuromyths that have been supported in prior studies were not endorsed by the participants of the current study, and some neuromyths were documented for the first time. Based on this observation, we propose three classes of neuromyths.

Discredited neuromyths were believed in the past but no longer. For example, prior studies have found that over 50% of pre-service teachers in the UK, Netherlands, Turkey, Greece, and China believe that we only use 10% of our brains (Howard-Jones, 2014). However, this neuromyth was believed by less than 50% of both our US and Korean pre-service teachers. Another discredited neuromyth appears to be belief in the Mozart effect.

Persistent neuromyths are incorrect statements that were believed in the past and continue to be believed today, even with widespread availability of disconfirming evidence. These include beliefs in the importance of enriched environments, sharp critical periods, overly strong differences between the left and right hemispheres, the effectiveness of Brain Gym-like physical exercise for improving cognitive function, and the effect of foods and drugs on brain development. Perhaps most strikingly, both US and Korean pre-service teachers had strong misconceptions about the importance of enriched environments, 17 years after Bruer (1997) critiqued extrapolating too far from animal research on this topic.

Emerging neuromyths are incorrect beliefs that were not measured in prior studies, but that the current study found to be widely believed. For example over 50% of US and Korean pre-service teachers believe that “blind people have better hearing.” Of course, we do not know whether belief in this neuromyth is increasing, for example because it is sometimes presented as true in television shows and movies, or whether it was widely believed in the past but simply not measured by prior studies.

This analysis reveals the promising successes of disappointing failures of the field’s (and the current study’s) attempts to reduce beliefs in neuromyths. The discredited neuromyths suggest that accumulated research evidence and careful scientific explanations can supersede incorrect generalizations about brain structure and function and its relevance for educational practice. The persistent and emerging neuromyths remind us that the job is far from done. An introductory educational psychology course was not a powerful enough intervention to dispel all neuromyths. This is perhaps not surprising. Correcting currently believed neuromyths or inoculating against future neuromyths requires providing knowledge of neuroscience concepts and processes sufficient to support valid application of laboratory findings to real-world problems. This is difficult even for trained scientists.

We conclude by noting an interesting difference in the neuromyths believed by US versus Korean pre-service teachers. US pre-service teachers more strongly believed the metaphor that the brain is like a digital computer, and more strongly believed in the interference of emotion on cognitive ability. We speculate that this difference stems from deeper cultural differences in beliefs about the rationality of thought.

6.3 Background factors affecting neuroscience literacy

With respect to the third research question, prior coursework in the biological sciences was not associated with greater neuroscience literacy or reduced beliefs in neuromyths in either US or Korean pre-service teachers. This was surprising given that the items on the neuroscience literacy survey were designed by other researchers and by ourselves to be relatively straightforward. So why didn't prior biology or neuroscience coursework help?

One explanation is given by analyses that point out the challenges of integrating information across neuroscience and education. Willingham (2009) argued that neuroscience concerns mapping cognitive functions to brain structure based on *isolation* from the environment, whereas education concerns the *interaction* between cognitive processes and the education context. This enforces an epistemic barrier between the disciplines. Devonshire and Dommett (2010) pointed out that neuroscientists work at multiple levels that differ in their relevance to educational practice. In particular, the molecular and genetic level are less applicable, whereas behavioral level is more applicable. Surprisingly, the lower levels are emphasized in educational psychology textbooks, with their colorful diagrams of neurons and synaptic transmission, whereas the higher levels are not. For these reasons, merely knowing neuroscience concepts and processes is not sufficient for successfully applying them to educational practice.

With respect to information sources, US pre-service teachers more frequently consulted books whereas their Korean counterpart favored public media – magazines and newspapers. It is possible that these different patterns of information consumption may explain the higher neuroscience literacy scores of US versus Korean pre-service teachers. Prior studies have found positive associations between reading neuroscience materials and neuroscience literacy (Dekker et al., 2012; Herculano-Houzel, 2002). We conjecture that books are more veridical sources of information because they are more often written by domain experts. By contrast, prior studies have also found that public media oversimplify neuroscience findings. Although this has a number of positive consequences, such as lower the barrier for learning about neuroscience research, there are a number of negative consequences as well. Public media often attract consumers by using fascinating neuroimages and seductive titles, but omit critical information about participants, conditions, tasks, and procedures (Poole, 2012; Satel & Lilienfeld, 2013). For the same reason, they often adopt an optimistic, not skeptical, interpretation of neuroscience findings (van Atteveldt et al., 2014). Finally, they are typically written by journalists who lack domain knowledge.

6.4 Increasing positive attitudes about educational neuroscience

With respect to the fourth research question, both US and Korean pre-service teachers had positive attitudes about applying neuroscience findings to educational practice. Prior studies have found that students, teachers, and policy makers want to know more about the brain (Herculano-Houzel, 2003; Oliver, 2011; Shonkoff & Bales, 2011). Consistent with this, the current study found that positive general attitudes about applying neuroscience findings to educational practice were positively correlated with neuroscience literacy scores at pre-test. We speculated that this might reflect a causal process where positive attitudes leads people to pay more attention to and learn more about neuroscience research, which results in greater neuroscience literacy. If this is correct, then encouraging educators' interests in neuroscience research might indirectly improve their neuroscience literacy.

6. 5 Opportunities and challenges for bridging education and neuroscience

Optimistic and pessimistic views in applying neuroscience findings to educational practice coexisted. Scientifically, education and neuroscience are different in methods, data, theories, and philosophy. However, if we create innovative research designs considering real context, make a proper reasoning across different levels of analysis, and do interactive collaboration between educators and neuroscientists, we can transform challenges as a potential opportunities in enriching educational practice and neuroscience research (Varma, McCandliss, & Schwartz, 2008).

Prior researchers have proposed bridging between neuroscience and education through the intermediary field of cognitive psychology (Bruer, 1997; Varma, McCandliss, & Schwartz, 2008). The current study explored opportunities and challenges of bridging through educational psychology instead. It investigated this for a novel population – pre-service teachers rather than the educational, psychological, and neuroscience researchers and policy makers that Bruer (1997) and Varma, McCandliss, and Schwartz (2008) addressed. Critically, it utilized an experimental design to provide the kind of causal evidence that thought pieces cannot: Taking an introductory educational psychology course increased neuroscience literacy (but had no effect on beliefs in neuromyths). For these reasons, we advocate for future research that uses educational psychology as the bridging discipline and pre-service teachers as the target population.

In greater detail, educational psychology and cognitive psychology both have important roles to play in bridging between education and neuroscience. Educational psychology is closer to education than neuroscience, with studies often implemented in classroom settings over multiple days, and addressing the efficacy of different instructional interventions. Cognitive psychology is closer to neuroscience than education, with studies often involving adult participants run in laboratory settings, with response times recorded. And finally educational psychology and cognitive psychology are close to each other, grounded in basic findings about memory and learning and demanding high levels of experimental control. For these reasons, we propose that both educational psychology and cognitive psychology must play important and distinctive roles in bridging between education and neuroscience (see Figure 3).

We speculate that one source of neuromyths is the certain distance that separates education from cognitive psychology, and cognitive psychology from neuroscience. The result is that the inferences required to apply findings across disciplines are prone to extrapolation. Inserting educational psychology into the picture decreases the distances between the disciplines involved, constraining inferences between them. In this new model, findings might originate in the neuroscience laboratory and might be extended to the behavioral level in the cognitive psychology laboratory. Rather than riskily trying to extend them to classroom instruction, the next step would be to evaluate their robustness in controlled classroom studies run by educational psychologists. If a neuroscience finding survives to this point, then it has a much better chance of surviving the final inferential leap, to deployment and evaluation in authentic classrooms.

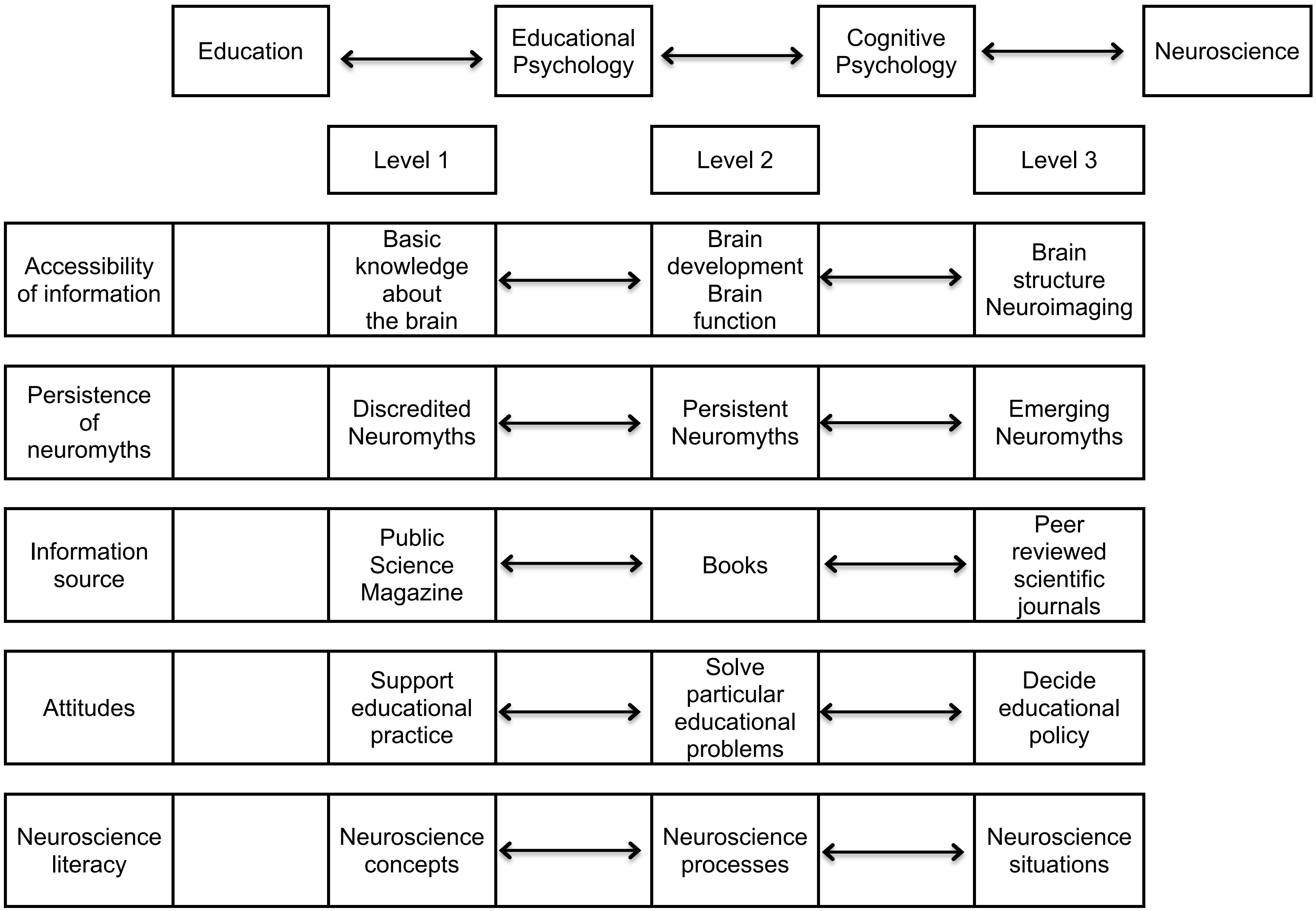

Figure 3. Three levels of framework for bridging education and neuroscience

6.6 Limitations and future directions

This study had several limitations and yielded some conflicting results, some of which were discussed above. These represent targets for future research.

First, the participants were pre-service teachers majoring in elementary education. We targeted this population because they have had less opportunity to learn about neuroscience compared to, for example, science teachers at the secondary level. However, this limits the generalizability of the results. Future studies should sample more broadly, for example contrasting pre-service teachers majoring in science or math education versus those majoring in social science or literacy education at the middle and high school levels.

Second, after taking an introductory educational psychology course, neuroscience literacy about brain structure and neuroimaging was no different at post-test than at pre-test. Future studies should investigate whether knowledge of these areas can be manageably infused into an educational psychology course, or whether they are too low level.

Third, taking the introductory educational psychology course did not reduce beliefs in neuromyths. It appears that merely learning about the brain is not enough to overcome incorrect prior beliefs. Future studies should investigate whether scientific reasoning skills can be directly addressed in introductory educational psychology courses, in particular validly interpreting different levels of analysis: neuroscience vs. psychological/behavioral vs. classroom/behavioral data. Future studies should also investigate direct interventions to reduce beliefs in neuromyths.

Fourth, contrary to our prediction, prior coursework in biology or neuroscience had no significant effect on neuroscience literacy and neuromyths. Future studies should collect more comprehensive data about prior scientific training at the secondary and post-secondary levels, to see if the added precision reveals the predicted relationship.

Fifth, we conducted this study in the US and Korea and utilized existing introductory educational psychology courses for our intervention. Although both courses were conventional in content (see Appendix B) and utilized standard textbooks, there were likely other confounding variables, such as the instructors' knowledge of neuroscience and views about its relevance for education. Future studies should try to more closely align the courses and their delivery to eliminate this and other confounds.

Last but not least, the current study used a quasi-experimental pre-post design without no-intervention group. To improve internal validity in evaluation of an educational intervention, future studies should compare changes of the neuroscience literacy and beliefs in neuromyths between groups with and without an intervention and evaluate the impact of other teacher training program courses on enhancing neuroscience literacy and reducing beliefs in neuromyths.

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Appendix A: Survey Questionnaire

Note: Incorrect Statements are in italics.

Please indicate your agreement with each of the following statements by marking “Yes”, “No”, or “Don’t Know”.

I. General knowledge (14 statements)

1. We only use 10% of our brain.
2. We use our brains 24 hours a day.
3. Brain size correlates with intelligence.
4. Blind people have better hearing.
5. Drug use causes holes in your brain.
6. Dreaming occurs continuously during sleep.
7. The brain is the organ that consumes the most oxygen.
8. You are born with all of the neurons you will ever have.
9. Listening to Mozart’s music makes you smarter.
10. Brain and mind are completely independent.
11. Memory is stored in networks of cells distributed throughout the brain.
12. Once you have experienced an event and formed a memory of it, that memory does not change.
13. Memory is stored in the brain much like as in a computer. That is, each memory is encoded in a tiny piece of the brain.
14. Bilingual education leads to confusion and delayed development, due to conflict between the two language systems.

II. Localization of brain function (8 statements)

1. Brain areas work independently.
2. Any brain region can perform any function.
3. Language is predominantly processed by the left hemisphere.
4. Right-hemisphere learners are more creative than left-hemisphere learners.
5. The left and right brains are connected by a bundle of nerve fibers called the corpus callosum.
6. Brief co-ordination exercises can improve integration of left and right hemispheric brain function.
7. The left side of the brain deals with rational thinking and the right side is emotional processing.
8. The left hemisphere mainly controls the right side of the body and the right hemisphere mainly controls the left side of the body.

III. Brain Development (10 statements)

1. Brain development involves the birth and death of neurons.

2. Brain development has finished by the time children reach secondary school.

3. Brain development occurs earlier for basic sensorimotor processes *such as vision and hearing,* and much later for higher cognitive skills *such as reasoning and planning.*

4. There are sensitive periods in childhood when it's easier to learn certain skills.

5. Teenagers' impulsive behavior is partially explained by incomplete brain development.

6. Environments that provide rich stimuli improve the brain function of pre-school children.

7. The brain continues to develop throughout adolescence, particularly in the frontal and parietal cortices.

8. Myelination, which improves the speed of neural communication, increases considerably throughout adolescence.

9. There are critical periods in childhood after which certain abilities can no longer develop and certain skills can no longer be learned.

10. Circadian rhythms ("body clock") shift during adolescence, causing pupils to be tired during the first lessons of the school day.

IV. Brain Structure (12 statements)

1. Your brain is gray.

2. Production of new neural connections can continue into old age.

3. The volume of blood in the brain increases with physical effort.

4. A wrinkle in the brain is added each time we learning something new.

5. Emotional stimuli are perceived more quickly than neutral stimuli.

6. Hormones influence the body's internal state, ***not*** *a person's personality.*

7. Glial cells support neuronal functions and modulate the transmission of signals.

8. Learning occurs through modification of the connections between neurons.

9. When a brain region is damaged, other parts of the brain can sometimes take over its function.

10. Emotional brain processes interrupt cognitive brain processes such as thinking and reasoning.

11. Each receptor site accepts only certain neurotransmitters, much like a lock accepts only a certain key.

12. Communication between different parts of the brain is through chemical substances and electrical impulses.

V. Neuroimaging (6 statements)

1. fMRI can measure the activity of a single neuron.

2. Brain activity can be studied through the oxygen consumption of brain areas.

3. The failure of an area to "light up" in neuroimaging means that it has no activity.

4. The brain area that is most active is the only one involved in some cognitive function

5. Neuroimaging depicts the correlation between brain activation and cognitive function.

6. Brain images are sophisticated reconstructions that depend on complex mathematical assumptions.

VI. Applying neuroscience results (10 statements)

1. Memory consolidation occurs during dreaming.

2. "Smart pills" can improve thinking and learning by changing the neurochemistry of the brain.

3. Drugs such as cocaine are addictive and affect the mind because they alter the chemical balance of the brain.

4. Children are less attentive after consuming sugary drinks and/or snacks.

*5. If pupils do **not** drink sufficient amounts of water (6 to 8 glasses a day) their brains shrink.*

6. It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement.

7. ADHD is an illness characterized by inattention and impulsivity.

8. Poor parenting is the main cause of ADHD.

9. Depression can be caused by the lack of certain chemicals in the brain.

10. Diseases such as Parkinson's and Alzheimer's are associated with synaptic loss and cell death in some brain areas.

Appendix B: Course Syllabus

	US - Santrock's (2010) *Educational Psychology (5th edition)*		Korea – Eggen and Kauchak's (2009) *Educational Psychology: Windows on classroom (9th edition)*	
	Topic	**Reading**	**Topic**	**Reading**
1	Introductory to educational psychology	1. Educational psychology a tool for effective teaching	Previews of educational psychology research in classroom	1. Teaching in the real world
2	Development I: Cognitive and language	**2. Cognitive and language development**	Cognitive development: language	**2. The development of cognition and language**
3	Development II: Personal, social, and moral	3. Social contexts and socioemotional development	Social and emotional development: Self-efficiency	3. Personal social and emotional development
4	Educational assessment I: Standardized tests	15. Standardized tests	Behaviorism: Pavlov, Watson, Skinner	6. Behaviorism and social cognitive theory
5	Educational assessment II: Classroom assessment	16. Classroom assessment and grading	Cognitivism and constructivism: Piaget, Vygotsky	2. The development of cognition and language 8. Constructing understanding
6	Individual variations	4. Individual variations	Personality and Social learning: Erikson, Kohlberg, Bandura	3. Personal social and emotional development
7	Sociocultural diversity	5. Sociocultural diversity	Individual differences: Gender, SES, Intelligence	4. Learner differences
8	Learners who are exceptional and special education	6. Learners who are exceptional	Special Education	5. Learners with exceptionalities
9	Behavioral and social cognitive approaches	7. Behavioral and social cognitive approaches	Classroom management and Principles of instruction	12, 13. Creating productive learning environments: Class room management, Principles of instruction
10	The information processing approach	8. The information processing approach	Attention, Memory, learning	7. Cognitive views of learning
11	Complex cognitive process	9. Complex cognitive processes	Motivation	10. Theories of motivation
12	Social constructivist approaches	10. Social constructive approaches	**Brain's structure: "Triune Brain"**	***Summary of Ornstein's (1995) The Amazing Brain Book***
13	Motivation	13. Motivation, teaching, and learning	**Information transmission in the brain**	***Instructor course contents***
14	Planning, instruction and technology	12. Planning, instruction, and technology	Assessment I	14. Assessing classroom learning
15	Final Exam		Assessment II	15. Assessment through standardized testing

Note: Bolded reading chapters include description and explanation about the brain function

Appendix C: Distribution of responses for each correct statement

a. US

Correct statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
I-2. We use our brains 24 hours a day.	87	87	7	10	6	3
I-7. The brain is the organ that consumes the most oxygen.	**63**	**81**	10	6	27	13
I-11. Memory is stored in networks of cells distributed throughout the brain.	64	64	13	23	23	13
II-3. Language is predominantly processed by the left hemisphere.	63	59	4	11	33	30
II-5. The left and right brains are connected by a bundle of nerve fibers called the corpus callosum.	84	83	2	7	14	10
II-8. The left hemisphere mainly controls the right side of the body and the right hemisphere mainly controls the left side of the body.	80	82	7	11	13	7
III-1. Brain development involves the birth and death of neurons.	56	63	23	23	21	14
III-3. Brain development occurs earlier for basic sensorimotor processes such as vision and hearing, and much later for higher cognitive skills such as reasoning and planning.	74	84	9	10	17	6
III-4. There are sensitive periods in childhood when it's easier to learn certain skills.	96	96	1	3	3	1
III-5. Teenagers' impulsive behavior is partially explained by incomplete brain development.	77	67	11	23	12	10
III-7. The brain continues to develop throughout adolescence, particularly in the frontal and parietal cortices.	90	89	4	3	6	8
III-8. Myelination, which improves the speed of neural communication, increases considerably throughout adolescence.	**49**	**80**	14	7	37	13
III-10. Circadian rhythms ("body clock") shift during adolescence, causing pupils to be tired during the first lessons of the school day.	42	49	20	10	38	41

Correct statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
IV-2. Production of new neural connections can continue into old age.	**51**	**67**	20	14	29	19
IV-5. Emotional stimuli are perceived more quickly than neutral stimuli.	**50**	**63**	13	13	37	24
IV-7. Glial cells support neuronal functions and modulate the transmission of signals.	40	39	3	8	**57**	**53**
IV-8. Learning occurs through modification of the connections between neurons.	67	74	6	9	27	17
IV-9. When a brain region is damaged, other parts of the brain can sometimes take over its function.	**76**	**93**	13	3	11	4
IV-11. Each receptor site accepts only certain neurotransmitters, much like a lock accepts only a certain key.	69	70	8	10	23	20
IV-12. Communication between different parts of the brain is through chemical substances and electrical impulses.	80	80	6	17	14	13
V-2. Brain activity can be studied through the oxygen consumption of brain areas.	57	63	1	4	42	33
V-5. Neuroimaging depicts the correlation between brain activation and cognitive function.	**50**	**66**	7	8	43	26
V-6. Brain images are sophisticated reconstructions that depend on complex mathematical assumptions.	**32**	**64**	11	22	57	14
VI-1. Memory consolidation occurs during dreaming.	56	50	4	13	40	37
VI-3. Drugs such as cocaine are addictive and affect the mind because they alter the chemical balance of the brain.	90	90	9	7	1	3
VI-7. ADHD is an illness characterized by inattention and impulsivity.	87	78	7	16	6	6
VI-9. Depression can be caused by the lack of certain chemicals in the brain.	90	91	4	3	6	6
VI-10. Diseases such as Parkinson's and Alzheimer's are associated with synaptic loss and cell death in some brain areas.	83	86	3	3	14	11

b. Korea

Correct statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
I-2. We use our brains 24 hours a day.	**60**	**74**	30	24	10	2
I-7. The brain is the organ that consumes the most oxygen.	68	62	6	10	26	28
I-11. Memory is stored in networks of cells distributed throughout the brain.	**48**	**58**	8	14	44	28
II-3. Language is predominantly processed by the left hemisphere.	**48**	**64**	16	10	36	26
II-5. The left and right brains are connected by a bundle of nerve fibers called the corpus callosum.	**56**	**80**	0	0	44	20
II-8. The left hemisphere mainly controls the right side of the body and the right hemisphere mainly controls the left side of the body.	92	90	6	6	2	4
III-1. Brain development involves the birth and death of neurons.	60	68	8	12	32	20
III-3. Brain development occurs earlier for basic sensorimotor processes such as vision and hearing, and much later for higher cognitive skills such as reasoning and planning.	**58**	**82**	4	0	38	18
III-4. There are sensitive periods in childhood when it's easier to learn certain skills.	80	90	2	8	18	2
III-5. Teenagers' impulsive behavior is partially explained by incomplete brain development.	**36**	**74**	26	20	38	6
III-7. The brain continues to develop throughout adolescence, particularly in the frontal and parietal cortices.	**42**	**66**	8	4	50	30
III-8. Myelination, which improves the speed of neural communication, increases considerably throughout adolescence.	**44**	**60**	14	0	42	40
III-10. Circadian rhythms ("body clock") shift during adolescence, causing pupils to be tired during the first lessons of the school day.	**48**	**68**	12	12	40	20

Correct statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
IV-2. Production of new neural connections can continue into old age.	30	40	38	30	32	30
IV-5. Emotional stimuli are perceived more quickly than neutral stimuli.	**60**	**76**	6	4	34	20
IV-7. Glial cells support neuronal functions and modulate the transmission of signals.	32	40	2	4	**66**	**56**
IV-8. Learning occurs through modification of the connections between neurons.	**66**	**86**	10	2	24	12
IV-9. When a brain region is damaged, other parts of the brain can sometimes take over its function.	68	62	14	32	18	6
IV-11. Each receptor site accepts only certain neurotransmitters, much like a lock accepts only a certain key.	**56**	**72**	14	10	30	18
IV-12. Communication between different parts of the brain is through chemical substances and electrical impulses.	86	86	0	6	14	8
V-2. Brain activity can be studied through the oxygen consumption of brain areas.	**58**	**72**	12	8	30	20
V-5. Neuroimaging depicts the correlation between brain activation and cognitive function.	52	66	12	8	36	26
V-6. Brain images are sophisticated reconstructions that depend on complex mathematical assumptions.	**56**	**68**	0	12	44	20
VI-1. Memory consolidation occurs during dreaming.	84	82	6	2	10	16
VI-3. Drugs such as cocaine are addictive and affect the mind because they alter the chemical balance of the brain.	86	84	4	8	10	8
VI-7. ADHD is an illness characterized by inattention and impulsivity.	90	94	6	0	4	6
VI-9. Depression can be caused by the lack of certain chemicals in the brain.	62	62	8	18	30	20
VI-10. Diseases such as Parkinson's and Alzheimer's are associated with synaptic loss and cell death in some brain areas.	**58**	**76**	10	2	32	22

Appendix D: Distribution of responses for each incorrect statement

a. US

Incorrect statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
I-1. We only use 10% of our brain.	40	36	**54**	**54**	6	10
I-3. Brain size correlates with intelligence.	11	9	**83**	**84**	6	7
I-4. Blind people have better hearing.	**61**	**57**	26	27	13	16
I-5. Drug use causes holes in your brain.	43	**50**	39	36	18	14
I-6. Dreaming occurs continuously during sleep.	41	39	**53**	**53**	6	8
I-8.You are born with all of the neurons you will ever have.	37	29	46	**57**	17	14
I-9. Listening to Mozart's music makes you smarter.	11	6	**63**	**74**	26	20
I-10. Brain and mind are completely independent.	17	13	**51**	**56**	32	31
I-12. Once you have experienced an event and formed a memory of it, that memory does not change.	13	6	**80**	**94**	7	0
I-13. Memory is stored in the brain much like as in a computer. That is, each memory is encoded in a tiny piece of the brain.	**61**	**67**	22	23	17	10
I-14. Bilingual education leads to confusion and delayed development, due to conflict between the two language systems.	3	8	**90**	**89**	7	3
II-1. Brain areas work independently.	16	10	**83**	**80**	1	10
II-2. Any brain region can perform any function.	8	30	**86**	**59**	6	11
II-4. Right-hemisphere learners are more creative than left-hemisphere learners.	40	40	34	31	26	29
II-6. Brief co-ordination exercises can improve integration of left and right hemispheric brain function.	**63**	**67**	4	9	3	24
II-7. The left side of the brain deals with rational thinking and the right side is emotional processing.	40	48	21	26	39	26
III-2. Brain development has finished by the time children reach secondary school.	14	10	**73**	**83**	13	7
III-6. Environments that provide rich stimuli improve the brain function of pre-school children.	**83**	**91**	7	4	10	5

Incorrect statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
III-9. There are critical periods in childhood after which certain abilities can no longer develop and certain skills can no longer be learned.	43	**50**	39	36	18	14
IV-1. Your brain is gray.	29	43	33	30	38	27
IV-3. The volume of blood in the brain increases with physical effort.	**54**	47	16	19	30	34
IV-4. A wrinkle in the brain is added each time we learning something new.	16	23	**56**	43	28	34
IV-6. Hormones influence the body's internal state, not a person's personality.	40	**52**	29	24	31	24
IV-10. Emotional brain processes interrupt cognitive brain processes such as thinking and reasoning.	**61**	**70**	19	9	20	21
V-1. fMRI can measure the activity of a single neuron.	31	23	16	27	**53**	**50**
V-3. The failure of an area to "light up" in neuroimaging means that it has no activity.	27	27	**51**	57	22	16
V-4. The brain area that is most active is the only one involved in some cognitive function	11	34	**50**	44	39	22
VI-2. "Smart pills" can improve thinking and learning by changing the neurochemistry of the brain.	8	10	**56**	**67**	36	23
VI-4. Children are less attentive after consuming sugary drinks and/or snacks.	**66**	**64**	21	22	13	14
VI-5. If pupils do not drink sufficient amounts of water (6 to 8 glasses a day) their brains shrink.	14	6	42	**57**	44	37
VI-6. It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement.	33	34	14	22	**53**	44
VI-8. Poor parenting is the main cause of ADHD.	1	6	**87**	**90**	12	4

b. Korea

Incorrect statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
I-1. We only use 10% of our brain.	34	36	38	42	28	22
I-3. Brain size correlates with intelligence.	12	12	**84**	**78**	4	10
I-4. Blind people have better hearing.	**80**	**78**	16	20	4	2
I-5. Drug use causes holes in your brain.	14	12	42	**50**	44	38
I-6. Dreaming occurs continuously during sleep.	46	24	46	**66**	8	10
I-8.You are born with all of the neurons you will ever have.	22	22	**50**	**58**	28	20
I-9. Listening to Mozart's music makes you smarter.	24	24	**52**	48	24	28
I-10. Brain and mind are completely independent.	26	26	**56**	**64**	18	10
I-12. Once you have experienced an event and formed a memory of it, that memory does not change.	6	4	**88**	**96**	6	0
I-13. Memory is stored in the brain much like as in a computer. That is, each memory is encoded in a tiny piece of the brain.	36	54	38	30	26	16
I-14. Bilingual education leads to confusion and delayed development, due to conflict between the two language systems.	30	34	48	**56**	22	10
II-1. Brain areas work independently.	38	28	**50**	**64**	12	8
II-2. Any brain region can perform any function.	12	10	**76**	**82**	12	8
II-4. Right-hemisphere learners are more creative than left-hemisphere learners.	**64**	**62**	16	18	20	20
II-6. Brief co-ordination exercises can improve integration of left and right hemispheric brain function.	**70**	**86**	8	6	22	8
II-7. The left side of the brain deals with rational thinking and the right side is emotional processing.	**82**	**80**	8	10	10	10
III-2. Brain development has finished by the time children reach secondary school.	10	10	**60**	**84**	30	6
III-6. Environments that provide rich stimuli improve the brain function of pre-school children.	**88**	**98**	0	2	12	0

Incorrect statement	Yes (%)		No (%)		I don't Know (%)	
	Pre	Post	Pre	Post	Pre	Post
III-9. There are critical periods in childhood after which certain abilities can no longer develop and certain skills can no longer be learned.	**66**	**88**	14	6	20	6
IV-1. Your brain is gray.	30	38	30	24	40	38
IV-3. The volume of blood in the brain increases with physical effort.	**74**	**86**	8	4	18	10
IV-4. A wrinkle in the brain is added each time we learning something new.	42	42	24	32	34	26
IV-6. Hormones influence the body's internal state, not a person's personality.	30	36	40	42	30	22
IV-10. Emotional brain processes interrupt cognitive brain processes such as thinking and reasoning.	26	24	42	40	32	36
V-1. fMRI can measure the activity of a single neuron.	22	20	6	14	**72**	**66**
V-3. The failure of an area to "light up" in neuroimaging means that it has no activity.	30	28	38	**52**	32	20
V-4. The brain area that is most active is the only one involved in some cognitive function	16	22	38	**54**	46	24
VI-2. "Smart pills" can improve thinking and learning by changing the neurochemistry of the brain.	12	10	46	**52**	42	38
VI-4. Children are less attentive after consuming sugary drinks and/or snacks.	**64**	**54**	24	20	12	26
VI-5. If pupils do not drink sufficient amounts of water (6 to 8 glasses a day) their brains shrink.	8	4	**50**	**66**	42	30
VI-6. It has been scientifically proven that fatty acid supplements (omega-3 and omega-6) have a positive effect on academic achievement.	**60**	46	8	12	32	42
VI-8. Poor parenting is the main cause of ADHD.	18	16	**50**	**66**	32	18