What Cognitive Neuroscience Tells Us About Creativity Education: A Literature Review

Kai Zhou
State University of New York at Albany

Abstract

Recently, an interest in creativity education has increased globally. Cognitive neuroscience research of creativity has provided possible implications for education, yet few literary reviews that bridge the brain and education studies have been published. This article first introduces the definitions and behavioral measures of creativity from cognitive neuroscientists' perspectives and provides a brief overview on the brain regions and neural studies on creativity-related cognitive processes. Second, the article examines neuroscience studies on the relationship between creativity and intelligence and discusses the nature side of creativity. Third, a comprehensive review of cognitive neuroscience studies on activities that may trigger new creativity thinking is provided, followed by a discussion on the nurture side of creativity--more specifically--how these findings inform creativity education. Supportive evidence from research in cognitive psychology and education are also presented. Then the article discusses the policy implications of the findings from the literature review as they pertain to creativity skills development in formal education and training.

Keywords

creativity, nature and nurture, neuroscience, skills, educational policy

Introduction

A growing body of literature has emerged on the influence of creativity on individual life and social economic outcomes. Research has shown that creativity is rewarded with wage premium (Gabe, Colby, & Bell, 2007), positive affect at work (Tavares, 2016), as well as health and well- being (Greaves, 2006). Policy-makers also have noted the critical role of creative workforce plays in transforming industrial economies to technology-driven knowledge economies. New technology-based companies and innovative start-up businesses which depend heavily on creative and skilled workers have a unique share in the economy, producing new jobs and contributing to economic growth of a country (Reynolds, 2010). The number of creative entrepreneurs who started small and medium-sized enterprises has grown rapidly, accounting for more than 10% of the labor market workforce in many countries (Fairlie & Holleran, 2012). Florida, Mellander, & Stolarick (2008) found that the creative class, who represent about 30 percent of the U.S.

Corresponding Author:
Kai Zhou, Department of Educational Policy and Leadership, State University of New York at Albany, 1400 Washington Avenue, Albany, NY 12222.
Email: kzhou2@albany.edu

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workforce, has significant positive association with regional labor productivity.

Given the importance of creativity in determining individual and social outcomes, the interests in integrating creativity and innovation development into the education system have been increasing (Sawyer, 2006). However, empirical studies have shown that creativity has little or no association with academic achievement (e.g., Ai, 1999; Balgiu & Adîr, 2014). It is therefore possible to say that either the creativity is not accurately captured by behavioral assessments that have been used by psychologists or creativity has not been properly measured by standardized achievement tests in schools. The uncertainty may hinder researchers, educators and policy makers from drawing out convincing educational policy implications from empirical work. Only recently, technology opened a door to more direct and comprehensive research on creativity. Cognitive neuroscience has emerged as an important approach that allows researchers to understand what happens inside the brain when performing creative tasks. The development of neuroscience may reshape the discussion on creativity education.

This paper is organized into four sections to provide an up-to-date review of cognitive and neuroscience research on creativity and discuss the policy implications for creativity education. The first section contains a brief review on the definitions and cognitive measures of creativity, as well as the brain regions and structures in creative cognition processes. The second section updates research findings on the relationship between creativity and intelligence and discusses the heritability of creativity. The third section focuses on the nurture side of creativity and presents neuroscientific evidence on activities that may trigger new creativity thinking. The final section discusses the use of neuroscientific research for policy implications as they pertain to creativity skills development in formal education and training.

Cognitive Neuroscience Research in Creativity

Creativity is "the ability to produce work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints)" (Sternberg & Lubart, 1999, p. 3). Boden (2004) classifies creativity into three types: combinational, exploratory or transformational based on the psychological processing features involved in innovative thinking. Combinational creativity involves combining familiar things and ideas in a surprising way. An example can be creating a new flavored cake by putting in unexpected ingredients. Exploratory creativity is realized by generating new ideas or artifacts within an existing conceptual space based on the established culturally-accepted rules and conventional style of thinking (Boden, 2013, p. 6). Improving the equipment efficiency by using better materials and creating new music are examples. Transformational creativity entails the creation of shocking things and ideas that were "impossible" before, which are beyond the existing conceptual space or specific stylistic limits. For example, the pioneering idea that the earth orbits the sun instead of the sun going around the earth was the result of disruptive creativity in ancient times. Exploratory and transformational creativity are both defined within a certain sociocultural space; ideas or artifacts are produced before they are recognized as "creative". Combinational, exploratory and transformational creativity can either appear in one innovative idea or artifact at the same time or separately.

Cognitive neuroscience depends heavily on analyses of associative pathways and relevance in human brain system during creative behaviors. Thus, cognitive psychologists and neuroscientists can carefully examine only combinational creativity so far. Because of the sociocultural features, exploratory and transformational creativity can only be explained through post hoc testing after the work is valued as exploratory or transformational creative (Boden, 2013). Exploratory or transformational creativity is far from being stimulable and their occurrence is rare. Though cognitive neuroscience studies can compare creative and non-creative individuals on their brain structure or the way of cognitive processing, the studies do not draw any causal conclusion on what factors affect exploratory and transformational creativity. Since the value of exploratory and transformational creativity has been more valued by the society, the lack of relevant neuroscience evidence on these two types of creativity makes it challenging to translate the brain findings into educational practice, not to mention initiating large-scale policy changes. Yet, the neuroscience approach has made some great contributions to the understanding of combinational creativity processes (Sawyer, 2012), providing a good start for cross- disciplinary discussions.

Neuroscientists use cognitive behavioral assessment of combinational creativity frequently in their studies to identify brain changes while people are engaged in cognitive tasks. The goal is to explain the combinational creativity thinking in a neurobiological way. On the cognitive behavioral level, creativity can be measured by a number of indicators: divergent thinking (McCrae, 1987; Runco & Acar, 2012), represented by originality (Beghetto, 2010); ideational fluency (Snyder, Mitchell, Bossomaier, & Pallier, 2004); cognitive flexibility (Ghacibeh, Shenker, Shenal, Uthman, & Heilman, 2006) and elaboration (Takeuchi et al., 2011); convergent thinking in making unique associations and solving insight problems (Arden, Chavez, Grazioplene, & Jung, 2010; Dietrich & Kanso, 2010); and vivid imagination (Karwowski, Jankowska, & Szwajkowski, 2017; Roberts et al., 2017). Various standardized behavioral assessments on creativity have been developed since the 1950s, among which the most widely used tests include the Torrance Test of Creative Thinking (TTCT) (Torrance, 1972), Alternative Uses Tasks (Guilford, 1967), Remote Associates Test (Mednick, 1962, 1971), and Creative Functioning Test (Smith & Carlsson, 1987). In a cognitive neuroscience experiment, researchers adopt a cognitive assessment and ask participants to perform a series of simple tasks. While a person is engaged in a task, brain activities are captured to show what's happening in the mind. Neuroscientists employ electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET) to study brain regions and neurons and explore the neural mechanisms underlying combinational creative thinking (Gabora & Ranjan, 2013). These technologies sometimes are applied together to provide more thorough understanding of the brain activities associated with cognitive functioning of creativity.

The theory of left-brain or right-brain dominance has been widely accepted by educators and policy makers. The right brain has been traditionally regarded as the prime organ that controls creativity and innovation. A number of right-brain training programs that involve art, music and drama, in particular, have been carried out to help young children "stimulate" right brain areas and "strengthen" their creativity-thinking functions. Nevertheless, no evidence from cognitive neuroscience has been found that a particular brain area for creativity exists (Sawyer, 2012). Creativity involves the whole brain. The right and the left hemispheres play a critical but disparate role at different stages of the creative process, and collaborate in different creative tasks, the same as they do for other cognitive function (Sawyer, 2012). When a person engages in creative thinking, the left hemisphere of the brain, which is dominant for analytic and verbal processes, works together with the right hemisphere, which is associated with natural perceptual, whole-pattern, spatial processes (Kaufman, Kornilov, Bristol, Tan, & Grigorenko, 2010). Though some studies have shown that the right and left hemispheres have closer communication and more dynamic collaboration during creativity activities (Lezak, 2012, p. 69; Whitman, Holcomb, & Zanes, 2010), creativity results from ordinary mental processes. Neural circuits coBrainmbine information in both creative and non-creative way (Dietrich, 2004).

The prefrontal cortex which is known for its "executive" functions in integrating complex information has been shown to be the central structure to enable higher-order processing, including but not limited to innovative thinking (Dietrich, 2004). The prefrontal cortex navigates attention, stores working memory and supports temporal integration (Funahashi & Andreau, 2013; Fuster, 2001). Already highly processed information from different sensory modalities is further screened and aggregated for higher cognitive functions, such as flexibility of cognitive control (Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005), reflective processing (van der Meer, Costafreda, Aleman, & David, 2010), and reasoning (Krawczyk, 2012) which are associated with creative thinking. The prefrontal cortex intentionally chooses what information an individual attends to and preserves the selected contents for a period that allows creativity to happen. Meanwhile, Dietrich (2004) suggested that the prefrontal cortex also acts like a search engine that can retrieve relevant elements from long-term memory stored in the temporal, occipital and parietal lobes (TOP) area to form new recombinations.

Brain study scientists have found that individuals who are highly creative are biologically different from those with low creativity. Carlsson, Wendt, & Risberg (2000) revealed that individuals who performed very well on the Guilford's Alternate Uses creativity test tended to have higher regional blood flow in both the left and right frontal lobes than those who got very low scores, which implied a positive association between activation of frontal cortex and creativity. This positive correlation was also confirmed by Gibson, Folley, & Park (2009) using a near-infrared spectroscopy (NIRS) method. The researchers compared creativity and frontal cortical activity between a group of trained creative musicians and a demographically matched control group. The results indicated that creative individuals experienced greater bilateral frontal activity than noncreative individuals while performing divergent thinking. Jung et al. (2009) found that the cortical thickness in a region within the lingual gyrus and left lateral orbitofrontal area was negatively linked to creativity, whereas higher cortical thickness in the right posterior cingulate and right angular gyrus was associated with higher scores on a creativity test.

Scientists also found positive associations between regional gray matter volume (rGMV) and several creativity indicators, such as ideational fluency, combinational fluency, originality, and cognitive flexibility in the precuneus (Fink et al., 2014; Jauk, Neubauer, Dunst, Fink, & Benedek, 2015; Kühn et al., 2014; Takeuchi et al., 2010). These neuroscientific findings provided evidence that creativity thinking ability is associated with brain structures. However, a snapshot of the differences between creative and non-creative individuals is not sufficient to get an insight of whether highly creative individuals were born with these different brain structures or developed them later in life through education and training. Longitudinal investigations are needed in the future to provide implications for creativity education and training.

Nature or Nurture?

There has long been an argument on whether creativity is a heritable trait or determined by the environment, and to what extent education can foster creativity ability. Some researchers claimed that creativity is a subcategory of intelligence (e.g., Guilford & Christensen, 1973) which has been found to have genetic origin (e.g., Posthuma et al., 2002). However, findings on the relationship between creativity and intelligence have been mixed. Some behavioral studies have shown that creative individuals are more likely to perform well on general intelligence tests (e.g., Barron & Harrington, 1981, p. 445). Others have found that intelligence is not a good predictor of creativity (e.g., Hocevar, 1980; Subotnik, Karp, & Morgan, 1989). Individuals who score high in the intelligence quotient (IQ) are not noticeably creative (Terman & Oden, 1959). Today, most researchers agree that creativity and intelligence are associated up to a certain point—around an average IQ of 120, while correlations in the higher IQ is negligible (Cho, Nijenhuis, Vianen, Kim, & Lee, 2010; Sligh, Conners, & Roskos-Ewoldsen, 2005). The current neuroscience literature on intelligence and creativity has further provided brain imaging evidence that intelligence lays genetic foundation for the occurrence of creative processes but is not sufficient to ensure the complex brain to exhibit creativity (Haier & Jung, 2008). Basically, most neuroscientists supported the claims that genetically reflected intelligence is largely responsible for the neural efficiency in the general cognitive functions (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007; Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004; Neubauer, Grabner, Freudenthaler, Beckmann, & Guthke, 2004), whereas environmental factors are mostly responsible for creative quality and output (Haier & Jung, 2008; Sawyer, 2012).

Since 1870s, twin studies have been used as one of the best approaches to evaluate the heritability of creative abilities. Most twin studies based on behavioral cognitive approach failed to reveal convincing evidence of a genetic basis for creativity (Sawyer, 2012, p. 181). For example, Reznikoff, Domino, Bridges, & Honeyman (1973) administered ten creativity tests to 117 pairs of adolescent twins. The subjects were divided into four groups—28 pairs of identical males, 35 pairs of identical females, 19 pairs of fraternal males and 35 pairs of fraternal females. The researchers didn't find proof of a genetic component in creative abilities. However, emerging evidence from brain imaging has told a different story. Schmitt et al. (2014) conducted a longitudinal study collecting 1,748 anatomic MRI scans from 792 healthy twins and siblings. Their findings indicated that both genetic and environmental factors had significant contributions to the variance in cortical thickness change in prefrontal cortex, which has been shown to be related to creative activities (Jung et al., 2009).

Some genetic analyses of creativity released recently also supported the existence of the nature side of creativity. Reuter, Roth, Holve, & Hennig (2006) proposed the first candidate gene for creativity through a test on 92 healthy Caucasian individuals while controlling for intelligence. They found that D2 Dopamine Receptor (DRD2) gene and Tryptophane Hydroxylase (TPH1) gene were associated with total creativity, accounting for 9% of the variance. Runco et al., (2011) replicated and extended the analyses to include a test on five candidate genes. They found that ideational fluency scores were significantly related to Dopamine Transporter (DAT), Catechol-O-Methyltransferase (COMT), Dopamine Receptor D4 (DRD4), and Tryptophane Hydroxylase (TPH1). Volf, Kulikov, Bortsov, & Popova (2009) identified the 5-HTTLPR polymorphism of the neurotransmitter serotonin transporter gene (5-HTT) to be associated significantly with divergent thinking. Other researchers have also found the genetic basis of creativity-related cognitive factors (e.g., Kéri, 2009; Smalley, Loo, Yang, & Cantor, 2005). However, though studies have shown a clear genetic basis for some creativity cognitive components, the extent to which the genes contribute to the manifestation of individuals' creativity is not within sight (Runco et al., 2011).

The cognitive neuroscience research is still in its infancy. How intelligence and creativity are distinctly or commonly expressed in the brain structures and regions, organization, and networks has not yet been thoroughly researched. The genetic contributions to creativity need further exploration through cross-disciplinary efforts, combining neuroscience with psychology, genetics, molecular biology and others. It's now generally accepted that all creative activities have a genetic basis. But creativity is a complex phenomenon that involves a large number of behavioral characteristics (Treffinger, 2009) and different cognitive processes in various brain regions and structures (Sawyer, 2012), each of which have interactions with the environment, the inheritability of creativity is limited to some extent (Barbot, Tan, & Grigorenko, 2013). Thus, we have good reasons to argue that it's possible to foster creativity from a variety of aspects through quality educational practices. Findings from brain studies in the near future may allow educators to target those underlying components of creativity and focus effort to achieve creativity education in school (Vartanian, 2013).

Neuroscience and Creativity Education

A substantial amount of evidence has accumulated to show the possibility of enhancing creativity via targeted cognitive education and trainings, most of which came from the analyses of behavioral data (Scott, Leritz, & Mumford, 2004; Tsai, 2013). Diversifying experiences (Ritter et al., 2012), episodic memory activation (Madore, Addis, & Schacter, 2015; Madore, Jing, & Schacter, 2016), improvisation activities (Sawyer, 2006; Sowden, Clements, Redlich, & Lewis, 2015) and puzzle based open-ended tasks (Ramaraj & Nagammal, 2017) are examples of creativity training that have been shown to be effective based on behavioral creativity assessments. But behavioral observations in creativity are limited in capturing the exact cognitive processing changes related to educational practices. Cognitive neuroscience research that examines both behavioral changes and how these changes correspond to the structural and functional changes in the brain is a powerful approach to provide insights about the intervention effectiveness in education.

Structural and functional plasticity in the brain in correlation with behavioral changes from education and training has been well documented (Vartanian, 2013). For example, Hyde et al. (2009) found significant changes in brain structures that are related to musically relevant motor and auditory skills after 15 months of music training. Rueda, Rothbart, McCandliss, Saccomanno, & Posner (2005) investigated the efficiency of attentional control training in neural network which involves the anterior cingulate in addition to lateral prefrontal areas. The researchers compared individuals with 5 days training and individuals with different types of no training and recorded the event-related potentials from the scalp during attention network test performance.

They found that the attentional mechanisms and their neural activities in the brain were malleable through intervention. The training group had significant improvement in executive attention and intelligence. Takeuchi et al. (2013) found that a 4-week working memory training program induced changes in functional connectivity and cerebral blood flow involving the default mode network and the external attention system during rest. Klingberg (2010) reviewed literature on working memory training effects and suggested that adaptive and extended training in working memory, which is fundamental to creative thinking, can lead to changes in brain activity in frontal and parietal cortex and basal ganglia, as well as changes in the density of dopamine receptor. All these neuroscientific findings have implied that education and training focusing on music, attentional control, and working memory can significantly change an individual's brain structurally and functionally. It can improve innovation-related cognitive skills, including motor and auditory skills, executive attention, intelligence and working memory.

There has been a growing body of research that examines the efficiency of creativity- related education and training by combining evidence from behavioral effects and the neural system underlying the transfer effects. For more than five decades, creativity education has closely bonded with the arts (Sawyer, 2012, p. 391). But criticisms have been raised that the creativity features in the arts education may not be transferable to other domains. Results from cognitive behavioral analyses on the association between music or visual arts education and cross-domain creativity were contradictory (Hetland & Winner, 2004). Recently, neuroscientists began to explore the cognitive benefits of arts education, providing evidence from the neural data of biological brain. For instance, Lopata, Nowicki, & Joanisse (2017) compared skilled musicians who had training in musical improvisation with individuals who had no formal improvisation training in their frontal upper alpha-band activity recorded by EEG during creative and non-creative tasks and objective ratings on creativity performances. They found that spontaneous processing of creative ideas can be effectively fostered through formal improvisation training. Similarly, Fink, Graif, & Neubauer (2009) investigated EEG activity in professional dancers compared to a group of novices with no comprehensive training in the field during performance of different creative dancing tasks. They found that professional dancers showed more right-hemispheric alpha synchronization then the novices did during improvisation dance tasks but not during imagining dancing tasks. The researchers also measured brain activity of the two groups during performance of the Alternative Uses test. They found that professional dancers showed stronger alpha synchronization in posterior parietal brain regions than novice dancers when performing the creativity test. These neuroscientific research findings have suggested that formal arts education may enhance creativity abilities, improvisation and generating alternative ideas in particular.

Brain imaging evidence on non-arts creativity education and trainings have also been documented recently. For example, researchers designed a 5-week creativity capacity building program (CCBP) as a targeted creativity intervention class offered to students at the Stanford Design Institute. The training program allowed participants to experience applied creativity, spontaneity, uncertainty and "failing fast," the reduction of bias and rapid prototyping through a cycle of five phases—observe, brainstorm, synthesize, prototype and implement, and participants were asked to repeat the cycle when necessary (Hawthorne et al., 2014; Kienitz et al., 2014). Researchers administered CCBP in parallel with a 5-week language capacity building training program (LCBP) as a control intervention, and measured creativity before and after the CCBP/LCBP training on the Torrance Test of Creative Thinking-Figural (TTCT-F) to examine the effectiveness of CCBP. Kienitz et al. (2014) found that CCBP resulted in significantly greater increase in the performance on two facets of creativity assessed in TTCT-F—resistance to premature closure and elaboration. Hawthorne et al. (2014) illustrated these findings further by investigating the neural correlates of creativity in both CCBP and findLCBP groups as reported. Another example is that of Sun et al. (2016) who implemented 20 sessions of cognitive stimulation to train individuals on creative thinking. Longitudinal analyses in this study showed that at the behavioral level, individuals performed better in both the originality and the fluency of divergent thinking after training. At the neural level, functional changes were found in the dorsal anterior cingulate cortex, dorsal lateral prefrontal cortex and posterior brain regions after the training. Increase in the gray matter volume in the dorsal anterior cingulate cortex was also observed after divergent thinking training. Neuroscience research has provided evidence that some short-term, well-arranged, non-arts creativity education and trainings are effective in improving individuals' creativity thinking. Educators and policy makers may consider introducing some practices into the classroom that were proven by neuroscience and behavioral research to be effective in creativity education.

However, studies that investigated the role of a specific creativity training or education play in both behavioral changes and neural manifestations of creative thinking are still very limited so far. As mentioned in the first section of this article, creativity depends greatly on integrated fundamental cognitive abilities developed from daily non-creative activities (Sawyer, 2012, p. 158). Creative thinking is linked to the activation of brain regions and biological changes that are associated with different fundamental cognitive processing activities, such as attention and working memory. Given the multi-facets phenomenon and the complex combination of ordinary cognitive features, many neuroscience implications for educational interventions on creativity improvement came from research focusing on optimizing attention and working memory.

Behavioral research has revealed that creativity is associated with a wider breadth of attention that allows individuals to collect more information at the same time (Kasof, 1997; Memmert, 2007). If individuals can attend to more things concurrently, they are more likely to have more diverse and a greater number of elements to combine, connect and construct, increasing the possibility of creative thought (Martindale, 1999). Creativity has also been found to be related to efficient selective attention that inhibits irrelevant information and facilitates relevant information to boost the production of original and useful ideas (Kharkhurin, 2011). Thus, cognitive training that helps expand attention and optimize selective attention may lead to better creative thinking (Takeuchi et al., 2013). Consistent with this notion, Liu et al. (2012) provided neural evidence on the potential cognitive benefits of attention training. The researchers investigated the activity patterns in the brain during the creative process—spontaneous lyrical improvisation for individuals who had free-style arts practice and the brain image results suggested that a state of defocused attention may enable the novel generation, characterized by disassociated activity in medial and dorsolateral prefrontal cortices. Additionally, in a fMRI study, Fink et al. (2010) found that cognitive stimulation via idea sharing with other people which could have resulted in a modulation of bottom-up attention can enhance originality. This creativity behavioral performance was found to be linked to increased activation in right- hemispheric temporo-parietal, medial frontal, and posterior cingulate cortices, bilaterally. Although there are few studies that analyze the neural and behavioral data together to examine the effectiveness of attention-creativity training, it's promising that creativity can be developed through well-designed training focusing on attention.

Researchers also found that working memory capability can predict a wide range of creative activities based on behavioral observations (e.g., De Dreu, Nijstad, Baas, Wolsink, & Roskes, 2012; Lee & Therriault, 2013). Recently, Vartanian et al. (2013) extended previous research by combining brain imaging and cognitive behavioral approach to examine the relationships between working memory training and creativity. They administered the Alternate Uses Task (AUT) creative test in the fMRI scanner in both experiment groups who received working memory training and the control group who engaged in a choice reaction time task that is not related to working memory. They found that the experiment group showed significantly lower activation in ventrolateral prefrontal and dorsolateral prefrontal cortices, which are known to be associated with divergent thinking, than the control group, even though performance variance on the AUT was not found between the two groups. The results suggested that a short regimen of working memory training can moderate prefrontal cortex neural function in divergent thinking.

In sum, cognitive neuroscience literature on the direct effects of training on creativity is limited. However, based on the results from fMRI and EEG studies of creativity-related training, researchers believe that it's very likely to increase neural efficiency in creative thinking through cognitive behavioral interventions (Vartanian et al., 2013). Brain studies have shown great possibilities in developing creativity through education.

Implications for Educational Policy

In this literature review, the main findings from the cognitive and neuroscience studies on creativity are the following: (a) Creativity is a complex construct defined within a specific sociocultural context and the neural techniques today can only explain a small part of creativity; (b) There is no particular brain area for creativity. Instead, creativity depends on integrated activation of brain regions and biological changes that are related to a variety of basic cognitive functions; (c) Creativity is heritable to some extent while it can be fostered through education and training; and (d) Creativity can be developed through arts education and systematic creativity training programs, as well as targeted training on fundamental cognitive abilities such as attention and working memory. Cognitive neuroscience has made significant progress in enriching our understanding of creativity and how to foster creative cognition. It has great potential for playing a role in education reform by providing brain-based implications for policy and practice changes that aim at creating a creative workforce in a knowledge economy.

There have been a growing number of countries that prioritize creativity learning in the education system. Many countries and regions, including but not limited to Austria, Belgium, Bhutan, Bulgaria, Czech Republic, Denmark, Estonia, Germany, Greece, Finland, France, Ireland, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Portugal, Republic of Korea, Romania, Singapore, Slovakia, Slovenia, Spain, Sweden, UK, Canada, and the U.S, have a similar agenda for the arts and creativity education but they differ in approach (Heilmann & Werner, 2010; Sharp & Le Metais, 2000; Zhou, 2017). For instance, Northern Ireland and Singapore include creativity in all curriculum areas, whereas the Republic of Korea emphasizes different aspects of creativity distinctively in the objectives of primary, lower secondary education and upper secondary education (Sharp & Le Metais, 2000). In its recent national education framework, Malta highlights discovery and creativity in its early education learning objectives.

Cognitive neuroscience studies have confirmed that educational training can improve an individual's creative thinking. However, not all educational practices in creativity development have been demonstrated to be effective. So far, many countries depend greatly on arts education to develop individuals' creative abilities. Some countries have integrated arts in other subject areas to reach a broader transferability of creativity skills (Heilmann & Werner, 2010). As mentioned earlier, a few brain studies have suggested that arts education may enhance creativity in general but current evidence is not sufficient to defend that arts education can generate cross-domain creative cognition skill. Instead of teaching creativity through arts education, neuroscience research had implied that general creativity education can be extended to focus on basic cognitive skills development in working memory and attention, which have been proven to be closely linked to creative abilities.

Despite the fact that neuroscience has continuously provided important scientific implications for educators and policy makers, putting brain-based theory or findings into universal classroom practice is still not near and challenging to reach. Many practitioners and policy makers fail to interpret and use scientific facts correctly. A bridge between neuroscience and education is lacking (Fischer, Goswami, & Geake, 2010) and neuroscientific messages are often distorted (Howard-Jones, 2014). To increase the impact from neuroscience on creativity education policy, it is necessary to communicate brain findings in an understandable way at all levels of the stakeholders and educate the general public (Akil et al., 2016). Meanwhile, given that creativity is defined within a particular sociocultural context, we will need to collect more neuroscience evidence from different sociocultural backgrounds. Currently, solid brain-based international studies that integrate both biological measurements and sociocultural information are very limited. There is a need for policy makers to identify a systematic assessment plan to evaluate curricular effectiveness of culturally different creativity programs. Then, educators can collaborate with educational researchers and neuroscientists to create a database that supports evidence-based creativity education.

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About the Author

Kai Zhou is a senior administrator and research analyst at Orange County Public Schools, Florida. She is also a doctoral candidate from the Department of Educational Policy and Leadership, University at Albany, State University of New York. Her articles have appeared in *European Journal of Education*, *The International Journal of Higher Education Research* and the *UNESCO Global Monitoring Report*. Her research interests are currently focused on the relationship between soft skills, education and labor market outcomes.