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Creativity and the work of art and science

A cognitive neuroscience perspective

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This chapter explores two questions, doing so, however, with the assertion that art and science are inseparable. The first question considers how both these areas of discovery and exploration have been such a fundamental part of what it is to be human. The second asks how communities can realize the potential of this creativity to improve engagement with *both* art and science.

We first consider how creativity emerged in human history and how strange our first creative approaches to science and art must have seemed to our early ancestors. Following this look to the past, we take up contemporary responses from cognitive neuroscientists whose research on the human brain extends our understanding of how learning in the arts and sciences develops. The chapter closes with a brief look at ways that some communities are acknowledging the potential of bringing the two fields together by bringing back pre-Enlightenment modes of operating.

Where did creativity come from?

As far back as philosophers have pondered the workings of the human mind, fascination with how creative learning happens has been a favorite topic. Aristotle, particularly in *Metaphysics*, seems to view as central to understanding how the mind works a consideration of the extent to which 'All human beings by nature stretch themselves out toward knowing.' He maintains that our love of the senses leads us to take in our experiences largely through the eyes, for 'we prefer seeing … as against anything else.' Only by seeing do we 'discover things and make[s] evident many differences' thus leading us to both knowledge and art that come from our experiences (1928: 1). Other philosophers of ancient times, as well as neuroscientists of today, agree with Aristotle, though today the emphasis is on *all* the senses and their generally unnoted role in how we come to know the world about us as well as our own bodies.

Humans have long expressed what they could not fully understand through art forms that sensually portray spiritual yearning. But these yearnings took them to map and study, celestial movements, animal behaviors, and ways of constructing safe enclosures for themselves. Early humans sketched and carved to express spiritual searching that reflected an affinity with land, sky, water, fire, and air as well as life forms that threaten, feed, and sometimes protect us (Morphy 1992; Oosten 1992). Groups living in highly diverse geographic settings etched into stone, bone, and, no doubt, other media, images of the animals around them and often created their gods in relation to themselves as well as animals other than humans who lived in their environment.

Humans have forever linked a quest for what lies beyond the instrumental and ordinary with spirituality. Yet only when organized sets of beliefs, such as Buddhism, Hinduism, Judaism, and Christianity, became institutionalized and ritualized did we accumulate multimodal living records of the extent to which human creativity affected daily life through both science and art. Architecture, carvings in stone, painted facades, and tombs enclosing jewelry, small sculptures, and bits of fabric tell us of the many ways our ancestors linked the wondrous gifts of the senses to their spiritual yearnings.

We know that creativity is uniquely human, in large part, because we are compelled to acknowledge the complexities of creativity. Other animals have the capacity for imitation, but we see little evidence of creative productions or performances from them. The mysteries surrounding the complexity of creativity have forever been with us, for we want to know what creativity is and where it comes from within us. Today and at many times in the past, we have desperately wanted to know where our own creativity may be taking us.

What makes creativity uniquely human?

Knowing has come to be linked to the powers of expression and innovation that all humans demonstrate. This creativity sets humans off from other animals. This setting apart, however, can best be explored through scientific developments that have led to technologies that allow us to know both the structures of the brain and how these structures work together when we undertake certain kinds of thinking or doing.

By the 1990s, a group of Italian scientists had tracked brain functions during occasions when monkeys took up actions they had observed in both other monkeys and humans. With later technologies approaching the capacities of functional magnetic resonance imaging (fMRI), scientists noted that, in general, higher-order primates, such as monkeys and chimpanzees, observed others and imitated their actions, facial expressions, and gestures. The neurons that indicated these imitative behaviors were dubbed 'mirror neurons,' since the behaviors of the observing primate mirrored those of the primate initiating the activity.[1]

However, only minimally and rarely did these higher-order primates create variations on what they observed to bring about innovative procedures and outcomes. This finding, like the early identification of 'mirror neurons,' startled scientists into looking more deeply into what they had not previously noted. Humans appear to be the only primates who insistently create from what they observe in the behaviors, gestures, or communication modes of others.

Aristotle was correct. Observing or seeing is fundamental to the human capacity to discover and consider differences. It is this capacity that scientists now understand to be fundamental to human creativity. Infants and toddlers show just how basic this capacity is when they imitate and create, but with intentions that differ from those they initially observed. This differentiating ability tells us that even the very young recognize that imitating has its limits, while creating has no such fetters. An eighteen-month-old observing an adult attempting to put two parts of a toy together but doing so unsuccessfully will repeat the action but successfully and with facial expression indicate intentions that differ from those of the model (Meltzoff 1995). Comparing and contrasting enable creativity and constitute ideas of originality that have grown up around all the arts and sciences.

Seeing activates perceiving, remembering, reliving, and redoing. Yet our ability to move forward from what we observe relies equally on our other senses that allow us to explore and discover even when we cannot, for whatever reason, see. We use touch to identify and locate objects, smell to discern conditions (such as dinner time or a fire), taste to identify and determine the state of substances, and we listen in order to communicate and to know what is happening around us. Moreover, what we sense leads us to undertake both art and science. Pleasurable sensations motivate us to create music, dance, and objects of pleasure that rely on both memory and expectation. Our senses guide the curiosity that we satisfy through scientific pursuits.

When we think of creativity, we think first of our hands. This is as it should be, for records of imitation by early humans appear first in crafted artifacts that remain. In the evolutionary history of humans, making and using tools first set us off from other higher-order primates, such as chimpanzees and baboons. Beyond simply imitating how others made tools, early humans fashioned original and improved designs. In doing so, they based design on judgments about effectiveness and durability. Tool-making led to widening activities that in turn eventually stimulated storytelling, through paintings and carvings as well as language.

Humans could make tools because of their innate primate capacity for *mimesis*, the imitation of actions and forms of expression that others undertake. This foundational primate skill evolved early. Humans took their skill to levels and activities that other primates could not achieve. Rituals and spectacles became forms of art added to paintings and carvings. Redesigning the local environment and increasing artifacts of daily life led to the need to describe, explain, and question what had been created and to seek means of improvement.[2]

As more tools and implements came into daily use, humans learned they could extend and specialize beyond what their hands and forearms could do. The haptic system, located most centrally in the hand, gives humans the tactile capacity to gain information and knowledge about objects and materials in the world around us. As we make with our hands, that touch extends what we can know, for the molding and changing of the substances we work with 'tell' us more than we can learn from mere touch.

In today's world where technology requires less use of the hand and much more of the fingers or the digits, the ability to create and to use tools that call on the entire hand and the forearm is decreasing not only in modern economies, but also in the developing world. Psychologists and evolutionary biologists point to the fact that from infancy, the brain responds as we engage our fingers, hands, and arms. The use of the hand to produce and translate into action structured symbol systems , such as language and numbers, reinforces the strong relationship we find in the learning sciences between doing and knowing, as well as between doing and representing through talk, writing, sketching, and building models.[3]

The mechanical capacity of the hand in tool-making, manipulating the environment, knowing the texture and nature of materials, and creating art forms as well as gestural sign systems shaped the brain's circuitry across our evolution. This growing capacity of the hand in harmony with communicational systems enabled humans to live in groups, develop products and trade, and generate Ways of moving and exchanging objects as well as recording interactions.

As the individual human develops from infancy, the hand is the primary instrument of both exploration and representation. A considerable part of the control apparatus of the human brain is specialized or dedicated to skilled use of the hand. The infant reaches out the hand to express desire; the infant learns to grasp in order to lay claim for the self to that which is beyond the self — an object or a finger of another. With their hands, young children learn to mold, shape, draw, and create motion. As they do so, they re-enact and represent fundamentals of the physical world, such as line, shape, color, and motion. Moreover, our signs and symbols have throughout most of human history been quite directly created and replicated through hand movement, either with or without tools. Neurologists have now concluded that language, numeracy, and symbol combinations develop very much in relation to the use of the hands and forearms as infants and young children create and construct beyond the individual self.[4]

Activities of exploring by using the haptic capacity of the hand ensure that individuals learn to develop a sense of autonomy as they mature.

Though we speak or write to show what humans know, the bulk of what we know and feel will never be expressed to others in language. Instead, we think, imagine, envision a scene, fret, and fear within our heads and hearts. We 'know that we know' even when we cannot or do not articulate in speech or put into writing what it is that we are thinking. It is hard work to convert our thoughts into language. We see this truth at work most easily in young children, but the same point pertains throughout the life span. Thought and language have different neurological origins. This means that fundamental to human learning is the fact that we shape thought in our minds and can gesture, sketch, draw, and model with our hands what we are thinking often before we can express ideas verbally. We can better articulate our thoughts when our nonverbal interior mental work has clarified and censored what we might then go on to express through the use of structured symbol systems, such as those of sign language, speech, or writing.

This reality results for us because the hand's symbol-structuring capacity runs along in front of the locomotor operations that support speech. Recent research, for example, has shown that individuals who 'know what they are talking about' use gestures that correlate appropriately with the thoughts they wish to express (Goldin-Meadow 2003). These gestures, however, are not necessarily structured symbol systems (such as sign languages are). The gestures we use to punctuate and elaborate our spoken language can be interpreted by viewers only quite broadly, with little specific agreement as to their meaning, for such meanings differ across cultures and languages. Here, as in our spoken languages, we have strong evidence of the creative powers of humans to correlate facial expressions and hand movements to go beyond what is expressed verbally.

With fMRI technologies, neuroscientists can for the first time understand what happens in those separate portions of the brain dedicated to visuospatial, verbal, or locomotor work when we grip, hold, touch, or speak of what we simultaneously see. The haptic or hand-guided feedback that children gain when they grip a crayon, pencil, or piece of charcoal enhances the act of mentally visualizing, of envisioning what lies behind or within the surface elements of what they see with their eyes. Children discover and explore with their hands and thereby supplement their visual powers that will as they mature contribute to their verbal powers.[5]

With maturation, children given opportunities for the hand work of art move into more creative and controlled representations, such as those involved in playing an instrument, sketching architectural designs, and fashioning puppets. As young artists and scientists use their hands to create more complex forms of art and even small experiments, they gain practice vital to improving their visual and auditory acuity and discernment of multi-layered details even in the midst of chaos, noise, and confusion. Such acuity in young learners shows up as an ability to focus — to be attentive and alert.

Cognition becomes grounded as young children gain practice in motor-dependent production of visual representations of what they are thinking, imagining, and planning (Barsalou 2010). The 'thinking hand' — as investigator and manipulator of the environment — calls on all the modal systems of the brain to produce representations (such as those involved in pottery and Woodcraft, for example) that result from shaping, grasping, drawing, and manipulating materials. As the hand goes about its work, the brain exerts what neurologists call 'force patterns' that lead the potter or woodworker, for example, to seek more information, to be guided by internally asking questions that guide next steps and future outcomes.[6]

In the United States, where even families living in poverty now strive to buy their children the latest in 'touch' technologies, such as iPads and mobile phones, young children no longer play with clay or finger paint. Schools no longer teach script, trading direct involvement of the hand and forearm called for in handwriting for the 'swipe' or thumb-tapping required by technologies. Child developmentalists are discovering that children who have little or no opportunity to draw, shape, and enact their thinking through visual, dramatic, and dance and the musical arts, are those who struggle harder to learn to transform their thoughts into language and to hold their visual and auditory focus. Moreover, early reading experts see that for these children moving information into long~term memory as well as into imaginative responses to what is going on around them seems especially difficult.[7]

Along with the dramatic increase in usage of digital technologies, children in modern economies are remaining indoors much more than their earlier counterparts. As a result, they have few opportunities to take in directly the textures, smells, and other sensual offerings of forests or beaches. They know less about the natural world around them, leaving them unable to include the natural world in their imaginary pursuits in either the sciences or the arts.[8]

A related loss to creativity for both the arts and sciences has been the decline in play among children in both modern economies and the developing world. Infants play before they reach the end of their first year of life. We accept that they do so with little thought about the complex mental operations that play involves. Through play, children learn to imagine as well as to make odd combinations using both what they have seen and all that they can envision. Once children begin to play, they almost always exercise their curiosity and explore, often discovering objects and tools with which they create forms of representation. Sticks, rocks, sand, water, and pieces of bark and wire become transformed into villages, forts, castles, dams, bridges, and pathways for play animals and motorways for carts, trucks, and automobiles. This creative work amounts to thinking through the hand, translating what has been both observed and experienced. Internal stories motivate what is created in play. Since children's play reflects creativity at work, adults often use children's play as a prompt for talk directed to the child. Critical in this exchange is the fact that adults ask children 'real' questions for which children are the experts. Only they can explain what they are imagining and what each object or pathway is in their play village or forest.[9]

The play of children (as well as adults) reflects the propensity of humans for sociodramatic or pretend-we-are-someone-else-somewhere-else play (Smilansky 1968). The practice of putting memory of human events together with visual cues and dialogue to create an imagined narrative has long been vital to human development. The hands work in gesture with tools and materials; gestures, facial expressions, and costuming come together, often with music and dance as well as video and visual arts, to portray someone else other than the onlookers or actors.[10]

In dramatic re-enactment, the brain plays a special trick that suggests the extent to which particular parts of the brain are 'wired' for specific activities — even when the same part of the body is involved. For example, portions of the brain involved in hand gestures that give expression, emphasis, and added meaning are not the same as those involved in the instrumental work of the hand in tool-making and using. In other words, the production of gestural expression, as distinct from instrumental action, takes place through linkage to language and emotive centers of the brain. These are not the same neuronal locations or connections we call on when we use a hammer to drive a nail or pick up a knife for a cutting action (Gilbert, Reiner, & Nakhleh 2005).

The most creative work of humans has been language. We often think of language learning as imitation, and children do develop their own language by hearing others talk and in particular by having other people talk directly to them from infancy forward (Weisleder & Fernald 2013). However, the brain has a special twist on language learning, for children do not imitate the talk of others, but instead they hear, interpret, and create from and with the words of others. In doing so, they show the special capacity that humans have for hearing language and surmising the structure and components of the system that puts together what they hear to make meaning.[11] When we produce language, imitation will not take us very far. We have to learn to be creators of each one of the languages we acquire. Otherwise, we would be parrots. Moreover, to be social, we must create language that works appropriately and effectively in highly specific circumstances and for different purposes. But to do this creative linguistic work, we build up reservoirs of bits of language that we then practice rearranging in different combinations to express variations of emotions, ideas, and personalities. We do so in sometimes unexpected ways.

Child language scholars have found that during the moments just before sleep, toddlers alone in their room replay verbally what they have heard and seen throughout the day (Bruner & Lucariello 1989; Nelson 1989). When they do so, they articulate the talk of others with vocabulary and syntactic constructions that exceed the linguistic competency they themselves produce in their everyday reality. Re-playing or re-saying does not even need an audience for the fluency factor to kick in, for the monologues of these children have no known immediate audience. Second-language learners achieve the same advantages when they take on roles in dramatic re-enactments.

Enactment also gives the opportunity to develop and advance what psychologists call 'a theory of mind' or recognition of the intentions, plans, and desires of others (Gopnik & Meltzoff 1998). Children who have ample opportunities for sociodramatic play gain experience in figuring out how others think and what is in the mind of another character (Heath 8: Wolf 2005). Adolescents and adults who take part in theater attest to the extent to which this same kind of enactment extends their capacity for assessing how the thinking processes of others operate. Developing a theory of mind leads humans to manage theories of action, causation, and consequence — all vital in both art and science. The suspense built through dramatic performances illustrates consequences that follow specific motivations and actions enabling onlookers to roll over and over in their minds different courses of action and outcomes that could follow particular courses of action.

For teenagers, taking part in sociodramatic work is especially important for developing the ability to foresee and envision their own futures as they formulate plans and consider possible consequences of risk-taking. Participation in joint creative enterprises, whether building a bridge of wood scraps or creating a backyard treehouse, builds within adolescents a reservoir of strategies for managing anger, forecasting outcomes realistically, assessing consequences, and avoiding circumstances likely to bring them disappointing or troublesome outcomes (Heath 2012). As school budgets reduce time in laboratories, theaters, and art studios for young people, they also reduce young learners' opportunities to take part in problem identification and solution-building.

In several modern economies, such as Finland, the United Kingdom, Australia, and the Scandinavian countries, educators and medical personnel promote participation in a variety of science and art opportunities that allow young people to play roles other than child or student. Thus community centers and youth programs offer robotics clubs, furniture design, video clubs, theater and visual arts. The foreshadowed thinking that comes with all types of science and art performances and exhibitions give the young critical practice in thinking ahead, designing and planning, and considering consequences, intended and unintended. [12]

Museums, cultural centers, and community learning environments

The primary argument of this chapter has been that humans are hardwired for creativity through the unique neurological functioning of the human brain. Because humans also have extreme facility with creating, managing, and learning from structured symbol systems, such as numerals and language, we can also link our individual experiences with cultural history. Thus we adapt and create through combining capacities that rest not only in current use of our visual apparatus, but also in our memories — often embodied as well as held in narrative recollections. Moreover, our neurofunctional capacities also rest very much in the unique abilities of humans to use their hands and forearms to make and use tools and to adapt environments.

Within the first decade after the opening of the twenty-first century, museums, cultural centers (such as theaters and symphony halls) transformed traditional views of these sites that had come about during the nineteenth and twentieth centuries. Before the Enlightenment, museums and theaters, in particular, had been highly participatory. Individuals learned 'close up' with exhibitions and performances. Learners could handle objects, take part in demonstrations of science at work, and sit or stand near the stage and sometimes on the platform of public scientific experiments as well as dramatic performances. In market towns, a low platform became the stage for actors, acrobats, magicians, and other performers, most of whom could only be seen and not heard, because of competing noise from braying donkeys, squealing pigs, and cackling chickens, as well as the wrangling of housewives and merchants. Spectatorship and a sense of 'being there' mattered. Onlookers gradually wanted to know what was being said in plays. As a consequence, literacy spread (Fishman 2004).

By the nineteenth century, however, museums and other cultural centers re-defined themselves along disciplinary lines: museums of science, history, visual art, theater, military affairs, and other specific topics. Visitors viewed exhibits passively. Primary activities were to look, read accompanying descriptive plates for exhibits, and occasionally listen to a lecture or docent tour leader.

In 1997, Tony Blair became England's Prime Minister. He set in place his vision of 'creative partnerships' for regenerating villages that had suffered the economically devastating departure of mines and mills. The partnerships linked science and the arts in both schools and community sites. These ideas continued beyond the term of his administration and took hold in sites such as the Tate museums in London and Liverpool. As a consequence, the Tate museums led the way for museums across England to lessen or eliminate short fieldtrip tours by schoolchildren. Instead, museums across the United Kingdom began to offer open studios, often lasting several weeks, and inviting learners of all ages and social classes to take part in topic-based workshops that featured artists and scientists working together. In Melbourne, Australia, museums dedicated to special interests and populations, such as moving images, migration, wool, and other specific topics, opened studios. Some museums devised a calendar of special clays and events for public participation and invited submissions from local residents for sponsorship in exhibitions that allowed visitors and curators, as well as local experts, to work together.

In the United States, museums and other community cultural centers, such as symphonies and theaters, moved slowly to re-define themselves as learning environments open to cross-class and cross-age participation. Gustavo Dudamel, a musician, who had as a child taken part in the movement termed 'el Sistema' in Venezuela, was the initiating force for these changes. In Venezuela, throughout the countryside, as well as impoverished urban neighborhoods, taking part in classical music, choral and orchestral, had become possible for all children, including Dudamel during his childhood (Tunstall 2012). When he rose to world acclaim as a conductor and was recruited to the Los Angeles Symphony, as well as other symphonies around the world, he promoted the spread of the 'el Sistema' idea. As a consequence, in several modem economies, including the United States, local versions of the idea developed. Parents and children living in communities with few resources, poor schools, and limited transportation began to know what access to professional musicians and dedicated practice meant. Participation on the part of children (and in some cases parents as well) spread rapidly, creating anew the idea that every child has the ability to learn and to create through music, a view that had been well in place in schools and religious organizations of the nineteenth and early twentieth centuries.

Some museums, especially those in science, began to shift to a strong creative and participatory framework about the same time. The Exploratorium in San Francisco opened a tinkering space as well as an after-school open studio in science, including cross-age individuals with varying levels and types of experience in the worlds of science. State and local museums created 'makers" spaces and sought new ways of bringing deeper meaning into museum visits for individuals with little previous experience in being a spectator in exhibition halls. Art and science were in all those instances inseparable.[13]

Museums explored numerous ways to attract and engage visitors. In March 2012, the BBC released a video intended as a postcard from travels in the United States. Entitled 'Crossing a St. Louis Street that Divides Communities,' the segment introduced viewers to St. Louis, Missouri by way of Delmar Boulevard. Showing the dramatic disparities in wealth, education, and opportunity on either side of the street, the video provided a dramatic illustration of contemporary divisions rooted in the racial history of the United States.

St. Louis is located in a state whose very admittance to the country was based on a compromise designed to preserve the balance between slave-holding and free states. St. Louis is also the city where the Dred Scott decision was handed down, a legal case in which an enslaved man sued for his freedom and lost on the grounds that he was not an American citizen, and that indeed citizenship could never include African Americans. Today, the St. Louis region remains heavily segregated by race (Gordon 2008).

St. Louis, Missouri is not unique around the world in facing divisions in its population; cities like Berlin and East London present parallel cases where the contemporary population still shows the scars of the history of a place. The Missouri History Museum, which stands only blocks away from Delmar Boulevard, is an institution that has taken an active approach to bridging these divisions.

Museum visitation, even after the Civil Rights Era, remained overwhelmingly perceived as an elite activity for communities of privilege. Moreover, for the African American community, history museums often served as harsh reminders of a national history positing African Americans as passive victims of a racist history (Bunch 2010). Many parents, even when urged by their schools to visit museums, felt they needed to protect their children from environments they may have experienced as degrading, unwelcoming, or even hostile. Visitation patterns became widely viewed as a call for museums to rethink themselves.

Yet schools in Missouri and most states still insist on fieldtrips for all students. As education reforms in the United States placed increasing emphasis on standardized testing results, local museums felt the pressure to be a 'day on' instead of a 'day oil' from school. The Missouri History Museum responded by revising its programs to place an increased emphasis on interdisciplinary learning, critical thinking, communication, and collaboration skills. The 'Gallery + Classroom' concept grew, in which students spent one hour in the exhibits and one hour in the museum's classroom in activities related to the gallery's contents. Harmonizing two features of every visit — learning and fun — demanded work that stimulated reflective practices for teachers, museum staff, and young learners.

Training museum personnel to be creative and imaginative presents challenges. For example, interns applying for work in the education life of the museum have to think creatively about what has been and is a reality. During interviews with potential interns, they are shown a bill of sale for a 13-year-old girl and asked how they would approach this object if asked to speak about it with a group of 13-year-old girls. Weekly training sessions keep employees reminded of the need for sensitivity and creativity in their work. Activities facilitate active learning experiences. In the 'Movement in Black and White' program focusing on racial history in St. Louis, the gallery tour sets the stage for the classroom experience which is a dance workshop. Students are asked to embody the racial history of St. Louis, often switching perspectives. The choreography calls forth the history of civil rights marches in which police sought to break up the protests by spraying protestors with fire hoses. In the dance workshop, students march for eight bars with invisible signs held above their heads. The next eight bars has students dragging hoses to spray water on the protesters, followed by eight bars in which the students stagger backwards as invisible water hits them. The goal is to pair the body with the mind in approaching this difficult history, all the while emphasizing the need to grasp multiple viewpoints.

An additional case of creative approaches pertains to an exhibition of quilts from Gee's Bend, Alabama, in which members of an African American community created highly dynamic, abstract quilting designs that run counter to mainstream American quilts. Museum staff created a puzzle version of a quilt on display, and this activity station was posed as a teambuilding challenge in which students had to put the quilt together as a group. The challenge of piecing together the large-scale puzzle forced participants to slow down, look closely at the quilt on display, and communicate with one another about how to put together the pieces in their hands.

A debriefing process about what it was like to work as a group helped young learners re-envision times when a focus on individual success impeded the progress of the group as a whole. Aesthetic enjoyment of the quilts joined with reflection on group processes of creative production.

Every museum wants visitors to slow down as they observe exhibitions, take in the accompanying written material, and move back and forth to make comparisons and to consider linkages across the exhibitions. To facilitate ways to slow down the visits of parents with their children, the Missouri History Museum devised a gallery activity called the 'Chain of Events.' Each young person received a picture of an object, laminated and attached to a carabiner. The staff member held a long plastic chain with years indicated along the links to serve as a timeline. In order to clip their objects onto the chain where they belonged, students had not only to find the objects, but also to make the connection between the object and text panel in order to find the year. Spreading out in the gallery to look for objects gave students a sense of discovery and creative adventure, speaking also to their thirst for freedom to look and learn on their own. Returning to the group and physically clipping the picture onto the chain gave young visitors a sense of active participation.

Conclusion

Aristotle and indeed, all writers who treat the topic of creativity, argue that seeing leads to thinking and acting. Both of these activities find expression not only through linguistic means, but also in the creation of objects, performances, and installations of art and science. Museums, theaters, and other cultural centers will increasingly become more like their earlier counterparts before Enlightenment. During those years, individuals came to cultural centers and found art and science in linkage with curiosities, narratives, and wonderment. Learners found themselves stimulated into thought and action, questioning and challenging what they saw, and departing these centers with an urge to read and learn more. Before the Enlightenment, museums did not cordon off the dynamism of the arts and science in combination. Stretching out 'toward knowing' thus became more of an individual pursuit than at any time in human history (Stafford 1997, 2007; Turner 2006).[14]

Today, the tight linkage of science and art is rapidly influencing creativity in communities. Cultural centers recognize similarities in the creative impulses and processes of scientists and artists and the extent to which technological innovation relies on their co-dependence. This chapter has, through its brief review of what cognitive neuroscientists are learning about large- scale neural integration, emphasized the potential for creativity that is, as yet, largely untapped in either art or science education in schools.

Historians of science and the arts reinforce implications from the findings of cognitive neuroscientists. They urge communal learning environments that demonstrate the powers of creative work in both art and science. The plea of one historian of science summarizes this view. Daniel Lieberman, a Harvard University biologist specializing in human evolution, proposes that we need several things throughout today's society to sustain a culture that is both scientific and artistic: 'The sense of individual wonder, the power of hope, and the vivid but *questing* belief in a future for the globe' (Holmes 2008: 469).

Notes

1 Numerous publications have told the story of discoveries related to mirror neurons and the initial skepticism with which research scientists heard the news. The Italian scientists who made the first discovery proved the power of patience, for during the 1990:, other laboratories imitated the work of their Italian counterparts and found that, indeed, mirror neurons existed in higher-order primates. Only two decades later, however, did scientists begin to note the conditions, nature, and extent of imitation in relation to creative actions. For a summary of the evolution of thinking on imitation and creativity, see Meltzoff & Williamson 2013.

2 The most extensive discussion of tool-making and mimesis appears in Donald 1991, 1993, and 2001. For a background account of the relationships between early tool-making and aesthetics, see Steen in Turner 2006, and also Wilson 1998.

3 Wilson 1998, Chapter 15, 'Head for the hands' offers extensive evidence of ties between 'in the body' knowledge and formal verbal representations of that knowledge. Further development of these ideas is also given in Donald 1991. Numerous treatises on early child development also underscore the relationship between learning structured symbolic systems and exploring and representing the world with the hands and forearms through gesture. See Chapter 6 of McNeill 2005, and Gopnik, Meltzoff, & Kuhl 1999.

4 Wilson 1998, Chapter 10, 'The articulate hand' explores these issues in detail.

5 Wilson, 1998, Chapter 5, 'Hand, eye, and sky' elaborates on the ways in which scientists learned about the close coupling of hand and eye movement. See also treatment of this issue by architect Juhani Pallasmaa (2009).

6 Gilbert, Reiner, 84 Nakhleh 2005 includes essays that treat the numerous ways in which visualization links to locomotor centers of the brain.

7 Hruby

8 Goswami 201 1 provide a summation of research that links hand work and other locomotor activities with comprehension in reading. 8 The deficits children experience when their exploration and discovery opportunities do not include the outdoors came first from Louv (2005), a volume with the memorable title *Last Child in the Woods*. Since then, national commissions in the United Kingdom and other modern economies have sponsored research on implications of the loss of creative work the outdoors offers children. See, for example, www.childrenandnature.org and the reports on 'natural childhood' at www.nationaltrust.org.uk (accessed December 2013). Some experts have used the term 'natural deficit disorder.'

9 Numerous studies of play underscore these points, and studies of higher-order primates, such as chimpanzees and monkeys who have been denied opportunities to play, reiterate the essential role of play in the development of the brain of these primates. See, for example, one of the first collections of essays on this topic, edited by Bruner, jolly, & Sylva 1976. More recent research has brought medical researchers and human development scholars together to understand the complexities involved in the learning that comes through play. The psychologist Brian Sutton-Smith has been a leader in this work; see Sutton-Smith 1979 and 1997, and Pellegrini 1995.

10 Heath & Wolf 2005, and Heath, Boehncke, & Wolf 2007, as well as Heath 2012 document multi-year studies of the linguistic and reasoning gains for children immersed in sociodramatic play in both school life and community experiences in sociodramatic play.

11 The most accessible coverage of language learning appears in Pinker 2007. Revelations surrounding the creative capacity of children with the language they hear are best summarized in Nelson 1989. See also Weisleder & Fernald 2013 on the effects on language proficiency and vocabulary of talk addressed directly to toddlers.

12 A multi-year study of grassroots community organizations focusing on the arts documents quantitatively the extent to which studios and rehearsal zones generate language critical to scientific thinking, assessment, and creative connections for adolescents. See Heath & Smyth 1999, and Heath 2012.

13 Across modern economies, the movement to connect the worlds of science and art grows. A bimonthly online magazine called *SciArt* in America was launched in August 2013. Many articles feature work by artists such as Jonathan Feldschuh, who was inspired by the Large Hadron Collider and the Brooklyn-based Deconstructive Theatre Project that merges ideas from neuroscience with technology in performance. Genspace with its open-to-the-community laboratory became a gathering point in art and science in New York City. In Massachusetts the Lab Cambridge developed similar possibilities where art and science merge in exhibitions, classes, and events. In the United States, the STEM to STEAM initiative pushed the idea of adding art to the 'hard science' core curriculum of Science, Technology, Engineering, and Math. There has also been a surge in scientific organizations funding arts projects.

14 Historians of both science and art have, in the past two decades, been urging a rethinking of the current emphasis on entertainment and amusements. In doing so, they point to the diminishing forms of creativity in museums, cultural centers, and the public commons. See Stafford 1997, and Holmes 2008 for treatments of what has been called the 'second scientific revolution,' a time when the arts and sciences came together in new types of development, including the explorations of James Cook and Charles Darwin, along with the deep involvement of artists such as Samuel Taylor Coleridge and William Wordsworth in writing about the benefits of the intertwining of all art forms with scientific developments.

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