To Think without Thinking
The Implications of Combinatory Play and the Creative Process for Neuroaesthetics

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The author considers combinatory play as an intersection between creativity, play, and neuroaesthetics. She discusses combinatory play as vital to the creative process in art and science, particularly with regard to the incubation of new ideas. She reviews findings from current neurobiological research and outlines the way that the brain activates various regions when creative, combinatory play uses conscious and unconscious cognitive and emotional processes. **Key words:** combinatory play, conscious and unconscious cognitive playful manipulation; creativity; stages of the creative process; neuroaesthetics

The rapid advances in neuroscience imaging and research have opened up opportunities for interdisciplinary investigation and the cross-pollination of many fields. The relatively new field of neuroaesthetics offers a particularly rich example. British neurobiologist Semir Zeki introduced the term in 1999 to describe research into the neurobiological and psychological bases and correlates for aesthetic experience.[1] The aesthetic experience includes, for example, the perception of works of art, the emotional responses to and judgments of beauty (and ugliness), and the evolutionary roots of art making. Because creativity and play are inherent to the larger concept of aesthetics, the field of neuroaesthetics reenvisions both their roles with regard to aesthetics. The new developments also raise questions about the neurobiology of the kind of thinking involved in the creative process.

Combinatory play describes the conscious and unconscious cognitive playful manipulation of two or more ideas, feelings, sensory experiences, images, sounds, words, or objects. In combinatory play, players experiment with hypotheses, they play with possible outcomes, and they adjust to unexpected results and even “failures.” These players compare, contrast, synthesize, and break apart disparate elements or constructs in the service of reenvisioning a larger whole.

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This kind of mental play uses both unconscious and conscious thinking: scanning various stimuli and information, perceiving patterns and clear or hidden similarities between things or ideas, and playing with their interconnections, relationships, and links. We owe the term "combinatorial creativity" to the British cyberneticist Margaret Boden, who explores creativity in her influential study *The Creative Mind: Myths and Mechanisms*.[2]

The essence of curious creative thinking and problem solving, combinatory play provides a fertile field for neuroaesthetic investigation into the direct link between play, imagination, creativity, and empathy. Understanding this link is important because imaginative combinatory play becomes a critical part of many artistic creations.

It is also easy to observe combinatory play at work in the history of inventions, innovations, and discoveries in mathematics, science, and technology. In the world of science, for example, Albert Einstein concluded that "combinatory play seems to be the essential feature in productive thought—before there is any connection with logical construction in words or other kinds of signs which can be communicated to others. . . . Conventional words or other signs have to be sought laboriously only in a secondary stage, when the mentioned associative play is sufficiently established and can be reproduced at will."[3]

Play is also a crucial component of other aspects of creativity such as thoughtful risk taking, perspective taking, agency, curiosity, wonder, joy in exploration and discovery, questioning assumptions, and seeing mistakes as opportunities to learn. Psychologist Steven Brown and philosopher Ellen Dissanayake claim that explaining aesthetics necessitates exploring the neurobiology of creating, perceiving, and participating in and receiving art—the universal drive to take pleasure in "making ordinary reality extraordinary" that is observable in song, ritual chants, and the sing-song playful exchange between a mother and infant.[4] All these abilities include imagination, self-reflection, empathy, and metacognition (the ability to think about thinking), as well as the ability to adapt to changing circumstances and to learn from experience.

The Creative Process and Combinatory Play

In a lecture in 1908 that later became famous as a treatise on inspiration, French polymath Henri Poincaré discussed the importance of unconscious sources of creativity based on his analysis of his own creative process in developing new mathematical understanding. He described his experience of insight—his Eureka! moment—in his discovery of the mathematics he called "Fuchsian functions" useful in algebra and trigonometry. This moment came after long, unfruitful, deliberate work at his desk.

> For fifteen days I strove to prove that there could not be any functions like those I have since called Fuchsian functions. I was then very ignorant; every day I seated myself at my work table, stayed an hour or two, tried a great number of combinations and reached no results. One evening, contrary to my custom, I drank black coffee and could not sleep. Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. By the next morning, I had established the existence of a class of Fuchsian functions, those which come from the hypergeometric series; I had only to write out the results, which took but a few hours.[5]

Nearly everyone has experienced the sudden solution, found while occupied with a completely unrelated activity such as bathing or washing the dishes. On one occasion, Poincaré, stumped by a problem and "disgusted" at his progress, took a seaside holiday. Out on a walk during this vacation, an "illumination" came to him with "suddenness," "brevity," and "certainty." Indeed, the history of science is strewn with such breakthroughs and flashes of insight. Archimedes famously leaped from his bath after discovering the displacement of water by the weight of objects and ran through the streets of ancient Thebes shouting "Eureka!" Swiss civil engineer George de Mestral hatched the idea for a clever fastener while walking his hunting dog in an alpine meadow; under the microscope he later discovered how tiny hooks on seed burrs had snagged the loops and twists in the dog's fur. De Mestral called his product, Velcro, a combination of the words "velour" and "crochet," and it duplicated the hooks and loops of natural materials. Solutions to problems in differential geometry and number theory came to the mathematician Jacques Hadamard semiconsciously "at the very moment of sudden awakening." His new solution, hatched in a dream, apparently lay outside of his previous lines of thought and inquiry.

Although not all discoveries and insights arise so suddenly or dramatically in all cases of combinatory play, the creative process involves the discovery of hidden similarities between two or more things or ideas making their connections and relationships clear. This ability to see these hidden similarities and hypothesize about them involves both understanding your own way of thinking and understanding generally assumed facts, along with the ability to think beyond those thoughts and facts by questioning the assumptions upon which they are based. This process clears the way for new connections to form, leading to new perspectives and possibilities that involve insight, problem solving, and illumination. These new perspectives promote invention, innovation, discovery, and creativity.

If Poincaré best summarized the four main stages of creativity, British social psychologist Graham Wallas first codified them into four discrete but interconnected stages.[6] (Many others have since discussed and modified these four stages, but they remain basically the same.)

The first stage is the preparatory phase or stage, involving conscious attempts to solve a problem using known methods. Such attempts usually prove unsatisfactory. During the second phase, the incubation stage, the conscious mind remains busy with other tasks but the unconscious mind keeps working on the problem, combining or playing with ideas in ways rational thought might inhibit. In the third stage, an "illumination" like Poincaré's turns on a moment of realization that results from both conscious and the unconscious thought but appears in a flash of insight. In the fourth stage, these new insights are tested, evaluated, and verified in a conscious and deliberate manner.

A critical insight emerges from the close examination of the creative process. At a particular point, forcing attention and not truncating the space and time for mental play actually inhibits insight and creativity. After the period of focused conscious attention involved in the first stage, the prepared mind seems to need to relax in the second stage and allow the unconscious mind to dominate and incubate the knowledge, experiences, and expertise already gained to make more remote and unusual connections. In other words, the brain needs to play with information freely. This kind of awake dreaming and diffused attention, a state of mind in which we think without thinking, seems so much a part of everyday life that we rarely take it seriously. In fact, it is not easy to let the mind wander deliberately. Still, doodling and daydreaming can be taught and developed as a skill.

Learning to focus on not focusing or concentrate on not concentrating constitutes a complex form of play of the highest order. Once mastered, this special, imaginative combinatory play frees the mind and enables a fluid blend of conscious and unconscious cognitive processes. This process is not only essential to creativity, but to the imagination, metacognition, and empathy, and it incorporates emotional and cognitive bodily self-regulation, unconscious and conscious scanning, processing and cognition, and fluid interconnections between the hemispheres of the brain.

Like the scientists I noted, the creative child, the musician, the innovative entrepreneur, and the valuable employee also find ways to play flexibly with different combinations of ideas. Some prove useful. *New York Times* columnist and author Thomas Friedman observed that Google searches for flexibility in those it seeks to hire: "The No. 1 thing we look for is general cognitive ability, and that's not IQ. It's learning ability. It's the ability to process on the fly. It's the ability to pull together disparate bits of information."[7] The company seeks this kind of openness because, again, creativity thrives in the playful interval between structure and free mind wandering where the mind is allowed to play with different combinations of ideas without forcing a conclusion.

Creativity and Combinatory Play

Creativity—the drive for connections and regeneration through new combinations—is the essence of life. Humans share this drive with all organisms at the neurobiological level; it is basic to our desire to attach and connect with others, to procreate, and to dream. This drive to generate meaning by relating one thing to another is also fundamental to the automatic and unconscious "connection making process" of learning. In many animals, especially mammals, creativity can be a form of curiosity and the drive toward discovery, play, and problem solving. However, in human beings creativity is characterized by conscious, deliberate connection making and imaginative play by the combining and recombining of elements, things, or ideas with the goal of creating something new.

The powerful drives generally associated with creativity exist alongside equally strong drives that work against creativity and toward conformity. Conformity, driven by the need for homeostasis, familiarity, security, and group affiliation gives us stability and predictability, both of which are critical for survival. But resistance to change makes individuals and societies wither and decay.

We can see the tendency to resist change in the discomfort many people experience when faced with two contradictory ideas. They find it difficult to avoid choosing one of the ideas as true and dismissing the other. In fact, entertaining both as valid is commonly called "cognitive dissonance" in psychology [8] This theory describes how the natural and usual response to internal discord is to simplify it to one solution or view; the simplification tends to eliminate all other aspects of the situation and thereby reduces the tension. But such reductionism also inhibits creativity because creativity, by definition, requires the disruption of established paradigms, patterns, and beliefs in the service of producing something new. Creativity exercises the imagination and playfully combines disparate elements while overcoming the discomfort and fear of change, uncertainty, ambiguity, and inconsistency—even to the point of celebrating paradox, puzzles, and the unknown.

In this way creative thinking involves an actual subjective experience of paradox, because it entails the ability to perceive and connect similarities in different phenomena and to identify the links that exist between seemingly incompatible frames of reference, ideas, feelings, images, sounds, or objects. This process includes the ability to discern similarities as well as differences between two or more objects, people, or ideas; the ability to question assumptions; the ability to make analogies and metaphors; and the ability to tolerate ambiguity and uncertainty to learn or discover a new idea. Creativity also would include the ability to envision or imagine what is not directly experienced or observed, involving such cognitive skills as abstracting and recognizing patterns; analogizing; multidimensional thinking; and playing with images, concepts, and frameworks in the service of synthesizing and making meaning that results in novel and original solutions, perceptions, expressions, inventions, or discoveries. Creativity also includes learning from experience and through imaginative play, which, again, includes combinatory play.

Creative interconnections reveal themselves clearly in language, which is itself a universal example of spontaneous and continuously evolving creative combinatory play seen in its novel idioms, neologisms, puns, rhymes, and jokes, as well as its various figures of speech such as metaphor, analogy, and simile. Figures of speech like these inform both our perceptions and expectations. They reflect everyday creative thinking and are the creative mechanisms for the linking of sensory elements with emotions. These are then linked meaningfully with words and so become the fabric of our being and identity.

All learning involves this basic tendency toward meaningful linking. As the twentieth-century Swiss philosopher and developmental psychologist Jean Piaget describes, new information becomes assimilated into preexisting schemas or systems of knowledge based upon similarities.[9] If a preexisting schema can expand enough to accommodate new information or link this new information to preexisting knowledge, then it gets included in that schema. If, however, there is too much difference between the new information and preexisting knowledge, the creative thinker will create a new schema to accommodate the new information.

We have an innate drive to discover the links between experiences, feelings, and ideas based on similarities and differences. These links combine and evolve into sequences that form patterns. Patterns are repeated, predictable similarities—some obvious and some subtle—among various things. Discerning patterns has proven basic to survival; evolution has taught us to scan for patterns to recognize whether something might benefit or threaten us. Play and art demonstrate this natural affinity for patterns in games such as chess, card games, and puzzles and in artistic expressions such as quilting, music, mosaics, and rhymes. Our pattern-seeking behavior is an essential part of creative thinking, although it can also produce false assumptions and biases when previous experiences lead us to beliefs we do not question. Inevitably, however, as we make meaning out of experience, a tension arises between the creative need to interpret patterns and the creative need to challenge assumptions. Metaphor, simile, analogy, and pattern seeking are part of the way we make meaning out of experience; they are playful acts that are essentially aesthetic experiences and that inform our imagination.

Imagination itself is the ability to think playfully about how something might be different from how it is or has been. In addition, finding links, connections, and patterns between apparently dissimilar things is essential to creative thinking and innovation. Creativity does not merely depend on the emotional ability to tolerate uncertainty, ambiguity, and not knowing but also on the ability to play with counterfactuals and to combine possibilities into alternative realities.

Thus combinatory play, an act of imagination that transforms existing or known facts, ideas, or elements into novel forms, is an essential component of creative thinking, inventiveness, and innovation. This process occurs at both the unconscious and conscious level simultaneously. The specific kind of thinking that involves imaginative combinatory play is not only foundational for creative thinking, but also plays a role in reflective thinking, problem solving, and critical thinking.

Play and the Developing Imagination

There are clearly defined functions for play in evolution and neurobiological development, and these functions range from practicing survival skills to developing higher-order thinking, such as imagination, pattern recognition, metacognition, empathy, and creative thinking. If we consider these to be the ultimate goals of education, then we need to think seriously about play—as developmental psychologists like Peter Gray have often emphasized.[10]

We see the importance of play throughout history and across all cultures. Everywhere in the world, play spontaneously occurs—between parents and infants, between children of all ages, and between adults—through the arts, athletics, and games, and in rites and rituals. Over the past century, an abundance of research has documented the importance of play for cognitive, social, and emotional development.[11] Much research also notes the similarities of the effects of play in social animals.[12] Extensive research also covers the serious emotional, psychological, and physical effects—ranging from Attention Deficit Hyperactivity Disorder (ADHD), to depression, to violence—of the lack of play.[13]

Creativity and imaginative play occur in an intermediate space between security and freedom. Both internal and external security offer the safety necessary to explore beyond boundaries and to play. Physically and imaginatively, the foundation for internal security lies in a child's early experiences with supportive parents. But based on the current neurobiological research about learning and plasticity, we also know that such security can be facilitated at any age and by anyone in a mentoring or teaching position. Security enables the mental and imaginative play associated with questioning and challenging assumptions, ideas, restrictions, and rules. This thinking outside the box can involve anything from words and labels to cultural beliefs and ideologies. Although we think of this questioning of assumptions and standard truths as fun, again, it can create anxiety, resistance, and defensive responses by bringing uncertainty and posing threats.

Creative thinking balances on the very structure it questions and tries to think beyond. This high-level mental play performs a continual dance between order and chaos. Too much structure creates rigidity, and too little structure creates disorder—both of which inhibit creativity. The ability to judge the relative balance between structure and free play is part of the continual process of creative thinking as situations, contexts, and people change over time. The essence of the creative process can be found in the fluid looping between deliberately focused, conscious thought and attention and deliberately diffused, unconscious thought and attention.

Imagination and Combinatory Play

Imagination is the action of forming images in visual, aural, cognitive, and emotional space of "what could be" or "what might be." Imagination asks not only if something or someone can be different than it is or they are, but what would that difference look like and what would happen if it occurred. Imagination is fueled by curiosity, wonder, and restlessness. It is a state of mind that plays with "I wonder" and "what-if" questions. Imaginative play is a form of higher-order reasoning that sees things as they are, then envisions multiple possibilities and the consequences of these possibilities. As the philosopher Martin Buber said, "Play is the exultation of the possible."[14]

Imagination involves symbolic representations of perception and experience for visual, kinesthetic, and aural play. This kind of imaginative play can be developed into a skill through practice. It is also clear that creative play is predicated on the study and mastery of both basic skills and information about the ideas, objects, or problems involved.

Imagination and creativity also engage both memory and projections into the future. Ideas, images, or events that are not directly experienced in the present are considered to be "psychologically distant." In a study on psychological distance, researchers found that the more abstract a representation, the readier our minds develop creative connections among its disparate elements.[15] In addition, studies show that when research participants thought about a distant problem, they came up with more possible solutions than when a problem fell closer to them in space or time.

Remembering and imagining have been found to employ a common network in the brain, one that uses many parts of the brain such as the thalamus, the occipital lobe, the hippocampus, the limbic system, and the prefrontal cortex—all of which involve memories, visualization, emotions, and abstract thought.[16] The creative imagination follows these pathways, but so do essential and powerful emotional states such as loss, regret, remorse, and guilt—all backward-looking emotions—and fear, anxiety, worry, or obsession, which appraise the future. When these states overwhelm the ability to self-regulate, they can shut down possibility thinking and lead instead to concrete thinking and a variety of defensive maneuvers.

If, however, an individual has the inner security and freedom to play in the world of imaginative possibilities, he or she can move beyond the bonds and bounds of reality and transform objects assumed to mean only one thing. In this way, individuals challenge assumptions and see new realities. This creates a path for figuring out how to make that new reality actual.

Imagination and Empathy

Imagination is also a crucial component of empathy because it involves imagining how another person might feel even if that person feels differently than you do. From this empathic perspective, you put yourself in another's experience without losing touch of your own feelings. Imaginative empathy is an in-between space where two separate, different, and, perhaps, opposing realities coexist.

This kind of moral empathic imagination both informs and is a product of creative thinking. It exists in the same intermediate combinatory space as other aspects of creative thinking like metaphors and analogies. Fulfilling relationships, working with others in groups, and flourishing in a diverse society, depend, in part, upon the ability to use empathy to improvise playfully.

Improvisation

Improvisation is a form of play generally considered spontaneous, although it is always based upon stored information, ideas, or skills within more or less well-defined parameters. Very often, improvisation arises in response to another person or group of people—for example, through rhythm or melody in music or language, or through rhythm, gesture, and movement in dance. Doodling and free-association drawing—or indeed even writing or speaking—can also be another form of improvisation.

Creative improvisational play entails listening—the ability to pay attention, observe, and recognize patterns—and the patience to wait one's turn, to resist acting impulsively. Gestalt psychologists called this restraint "resistance to premature closure,"[17] and we now use it in assessments of creative thinking. Creative thinkers typically resist the impulse to close an open space immediately or respond to a question or problem quickly with the easy, familiar, obvious, right answer, driven—as I noted before—by the discomfort of leaving a problem unsolved.

Improvisation involves making something from that which is at hand, creating something through imaginative combinatory play with the materials provided and within the constraints imposed. Creative imaginative combinatory play involves mental, imagistic, and empathic improvisation, and creative combinatory improvisational play is sensory, kinesthetic, and physical.

The Four-Stage Creative Process, Combinatory Play, and Neurobiology

I should note that the four stages of the creative process—preparation, incubation, illumination, and verification—are not linear; they are stages in a cycle that often continues to inform yet another cycle, or a series of cycles. Mastery of the skills inherent in each of these stages applies creative problem solving in many arenas—personal relationships, the arts, ethics, science, technology, and others.

Thinkers about creativity mainly focus on first stage—preparation—probably because they find it easier to address and easier to assess. But preparation is only the beginning of a creative process that proceeds through incubation, illumination, and verification. Let me briefly describe the fourfold process.

Preparation

The preparation stage of the creative process lays the foundation for creative breakthroughs and insights. This can include a variety of activities—practice, rehearsal, repetition, research, questioning, and observation. This stage is often difficult and tedious because it entails immersion in a problem and includes asymmetrical critical and analytical thinking, identification of purpose, and realistic assessment. At this stage, players consciously explore many hypotheses and engage in disciplined, prolonged study. Here they benefit from the help of a mentor, but they may also rapidly master information and practice relevant skills that include such elements of emotional intelligence as self-regulation and the ability to tolerate frustration and to delay gratification.[18]

Incubation

This critical stage of the creative process involves a shift from the dominance of deliberate, conscious processes to a dominance of unconscious processes. There are two important kinds of unconscious thinking at this stage: one is reverie, a form of free-floating attention toward external stimuli; the other is an internal process making playful connections between previous experience and stored knowledge. This second kind of unconscious thinking usually involves, like reverie, a physical break from deliberately focused work, and it involves being engaged in something other than the problem at hand. It can involve dreaming or, like reverie, daydreaming. Both of these forms of unconscious thinking can be volitional, but often frustration, mental overload, or dissociation signals the need to shift to these states of mind. An individual can learn to read these physical, mental, and emotional signals indicating the need to take a break and engage in physical or mental play that allows for integrating information. This incubating ability can actually be taught but teachers have to learn to recognize the signals that a student or group might need it. The skill itself, rarely taught, has important pedagogical implications for effective learning and classroom management.

Current research links unconscious thinking with the Default Mode Network of the brain system that is important for both creative thinking,[19] and self-regulation. This system includes brain regions that become more active when it focuses on the internal as opposed to external world. Some psychologists describe it as a state of "wakeful rest." This state becomes active in daydreaming, remembering, imagining the future, and considering alternative realities. Conscious meditative states, reverie, and imaginative play, as well as sleep and dreaming, are critical for the synthesis of the various kinds of information individuals learn. Researchers hypothesize that brain trauma does long-term harm to these integrative functions, which may explain why we commonly find that children who have experienced such trauma lose the ability to play.

The space created allows the unconscious to play with combinations that may not have entered the conscious mind because they are not logical or do not make sense and because the immersion necessary does not permit psychological distance and perspective. This is called "bilogical" play and involves two separate sets of logic: that of the unconscious mind and that of the conscious mind.

Research in unconscious mental processes by social psychologists Ap Dijksterhuis and Teun Meurs found that individuals who were distracted while in the process of responding to a problem came up with more creative or unusual responses than those who answered the prompt immediately.[20] They concluded that allowing the mind to wander (disconnecting from conscious focus) allows unconscious thought to play associatively and then to reconnect to memory and consciousness with novel solutions. This highlights the importance of the incubation stage in creative problem solving regardless of whether the time spent in this stage be seconds or days.

Jonathan Schooler[21] conducted another study validating the connection between mind wandering and creative insight. He found those who spent a period of time engaged in undemanding activities that facilitated mind wandering performed better on tests of creative thinking. A follow-up study confirmed these findings among creative individuals including physicists and writers.

For incubation to work, the unconscious mind must be allowed to scan and play with information that may seem irrelevant to the conscious mind. Recent research by the Harvard psychologist Shelley Carson and her colleagues[22] found that highly creative individuals show reductions in what their study called "latent inhibition," which refers to "the capacity of the brain to screen from current attentional focus stimuli previously experienced as irrelevant."[23] These reductions in latent inhibition are associated with an open personality, divergent thinking, and creative achievement. Carson and her coworkers concluded that "the highly creative individual may be privileged to access a greater inventory of unfiltered stimuli during early processing, thereby increasing the odds of original recombinant ideation."[24]

The ability to reduce latent inhibition seems crucial for creative thinking in any area, but, at some point, this openness and receptivity must be allowed to slow and to take a rest, thereby allowing the unconscious mind to assume full control. The inward focus of this kind of resting has important correlations with psychologist Mihaly Csikszentmihayli's concept of "flow,"[25] which is characterized by immersion, by the intensity and joy of focusing completely on one activity.

Recent brain-imaging research about insight shows that activity in the left frontal cortex slows and the visual cortex shuts down completely in the moments before a flash of insight occurs with a burst in the right temporal lobe (the so-called "Aha!" moment).[26] This suggests that the brain needs to cut out external sensory input to increase connections between the conscious and unconscious mind and to let it play. Researchers have identified a preparatory phase during which the visual cortex goes silent—the brain is focusing on a problem and shutting out distractions. Then comes the search phase, still involving the areas of executive control. After a time, insight appears as if out of nowhere.

In a study investigating the brain activity of jazz musicians engaged in improvisation, Johns Hopkins otolaryngologist Charles Limb and his colleagues found that a large portion of the prefrontal cortex responsible for monitoring performance shuts down completely during improvisational playing while a smaller portion of the prefrontal cortex involved with freer self-initiated ideas and impulses becomes more active.[27] The study found that shutting down inhibitory brain functions as well as external sensory and informational stimuli allowed spontaneous creative combinatory play.

I find the work of cognitive neuroscientist Elkhonon Goldberg regarding hemispheric specialization for cognitive novelty and cognitive routinization particularly interesting for understanding of the role of the right hemisphere in the incubation stage of creativity.[28] Goldberg discovered that the right hemisphere becomes active when stimulated by a novel task and that, in addition, the right hemisphere seems to be more dominant in solving problems involving insight and the processing of new or remote associations. As the novel stimulus becomes routine, the activity in the right hemisphere diminishes, and the left hemisphere fires up. Goldberg concluded that, "the relationship between the two hemispheres must be dynamic, characterized by a gradual shift of the locus of cognitive control over a task from the right hemisphere to the left hemisphere."[29]

This research and an awareness of the importance of incubation as a part of learning as well as of creative and critical thinking has important implications for educators. Teachers need to differentiate a daydreaming incubation state—during which a student synthesizes information—from disrespect, distraction, sleepiness, boredom, or a lack of understanding. Teachers also need to recognize the importance of the timing of learning and the need for building in breaks and play time.

At the incubation stage, a more hidden part of the creative process, a mental space opens within which the mind can play with combining and recombining ideas. This space allows combinations that the conscious mind might not recognize because they do not make sense or they seem absurd or impossible. The psychologist J. P. Guilford calls mental play that often involves making analogies and associations "divergent thinking,"[30] and physician and creativity consultant Edward De Bono calls it "lateral thinking."[31]

The incubation stage demands a suspension of traditional modes of thought and reasoning and a willingness to question ideas assumed true. And it calls for an ability to withstand the upheaval and uncertainty caused by questioning. After a period of focused attention, the brain seems to need relaxation to allow the right hemisphere to dominate and make remote and unusual connections—in short, to play with stored and learned information and experiences. (At a certain point, forcing attention on the problem will actually inhibit the creative process necessary for insight.) At this stage, the unconscious mind is freed to scan for patterns, similarities, and differences, and it makes connections between different matrices of thought that have their own internal logic even if they appear incompatible to conscious logic. According to the Hungarian author and journalist Arthur Koestler in his writing about creativity,[32] these seemingly incompatible matrices of thought are then able to be "bisociated," resulting in a new and novel idea.

Insight and Illumination

The illumination stage, which precedes and informs action, is not so much a stage as a moment of sudden awareness and synthesis that is conscious, the one —again—we call "the Aha!" moment. This synthesis and insight derives from preparation and incubation and results from recombining ideas and knowledge that might come from anything—an invention, a theoretical discovery, a joke, a metaphor, a work of art, or a new idea.

Here fascinating research regarding the right hemisphere of the brain, conducted by cognitive psychologists Mark Jung-Beeman and John Kounios, supports theory.[33] They studied electroencephalograms (EEGs) of individuals' brains to pinpoint moments of creative insight and found that the first areas activated in problem-solving were the prefrontal cortex and the anterior cingulate cortex. In the preparatory phase, as I have discussed, the visual cortex appears silent, and the brain focuses on a problem, shutting out all distractions. Then in the search phase, the areas of executive control become active, and a little later insight appears seemingly out of nowhere. Remarkably, Jung-Beemon and Kounios found that a small area in the right hemisphere became active the second before the insight was experienced consciously. And this area (the anterior-superior temporal gyrus) has been associated with some aspects of language, particularly in generating metaphors and jokes.

Another recent study shows that individuals who solve problems through insight have different brain patterns than those who do not.[34] This research illuminates the activity of the brain while it daydreams or the mind wanders. Contrary to what many believe, the brain is *most* active when the mind is at play or wandering, certainly more active than during focused reasoning on a specific problem.

Verification

Verification signifies the point in creativity at which the focus moves from an internal to a more external process. This stage might include a critique, an assessment, and, possibly, a reality check. The mind comes to understand and reflect on the idea or action, to assess it, and put it into context. This marks the beginning of conscious, deliberate research and experimentation to evaluate further the usefulness of the new solution, its rejection, or its revision. Here, insights often involve the awareness of a need for further work or study, thus looping back to stage one, the preparatory frame of mind.

Summary

The creative process moves from predominantly conscious, focused attention, work, practice, and experimentation to various forms of conscious and unconscious thinking, and on to unconscious combinatory play, punctuated by moments of synthetic conscious awareness and insight, and then back to conscious critical analysis. It constitutes a bottom-up, top-down feedback loop that involves all parts of the brain, including both hemispheres, different parts dominanting at different stages of the process.

At the macrolevel and as history, this process looks like the one presented by historian Thomas Kuhn in his description of the world's pivotal scientific revolutions.[35] For Kuhn, thinkers like Copernicus, Newton, and Einstein engineered paradigm shifts that resulted in fundamentally new ways of viewing how the world operates. At the microlevel, cognitive and organizational psychologist Teresa Amabile refers to this as "breaking a mental set" that allows one to move out of one conceptual mindset and into a new one. [36]

Flexibility like this requires emotional regulation and the ability to tolerate the states of ambiguity, the nonknowing, of the incubation stage. In fact, there is increasing evidence from neurobiology about the importance of emotions for rational decision making.[37] According to this research, access to, knowledge of, and management of feelings proves indispensable in making choices and selecting data out of a store of information. In addition, the connections from the emotional systems to the cognitive systems are stronger than from the cognitive to the emotional.

The ability to tolerate frustration and ambiguity and to delay gratification provides an essential foundation for: the discipline and motivation it takes to learn and master the essentials of a given domain of inquiry; the ability to put aside a problem and let it incubate rather than fixing on an immediate solution; the ability to let go of one's initial hypothesis to explore a new possibility; the ability to withstand the upheaval caused by questioning belief systems and assumptions; and the ability to learn from and acknowledge mistakes. In addition, the emotional self-regulatory functions I have described allow a temporary suspension of consciousness and permit unconscious "work" to be done that often takes the form of visual images prior to formulation in any language.

Therefore, the education of any science, math, or art student should include exercises in accessing their imaginations and in using their experiences from other domains to facilitate analogy-making synthetic thought. These could include exercises in particular art forms addressing all the different intelligences, in visual thinking, in seeing analogies with regard to patterns across different domains, and so forth. In addition, we should pay attention to the development of the emotional skills discussed earlier and, for example, give students time for play, reward their not knowing, and applaud their looking at problems from multiple vertices.

Implications for Neuroaesthetics

As a subject in the field of neuroaesthetics, combinatory play offers several areas to explore. For example, it would be interesting to discover if the state of combinatory play and "awake dreaming," the reverie which is indicative of the incubation stage in the process of creating, is also engendered in those who engage with works of art. It would also be fascinating to build on Charles Limb's work about the changes in brain states while creating and improvising in any art form, as well as while experiencing works of art in all modalities.

Much research already exists about neuroplasticity and training in various art forms. Because it seems clear that the creative process of combinatory play has to do with fluid interconnectedness between hemispheres and between brain regions, it might be important to explore what kinds of training and education develops or inhibits this ability to move cognitively and affectively between states of attention. For example, plastic changes have been shown to occur especially in the brains of musicians. Electrical engineer and psychiatrist Christian Gaser and neurologist Gottfried Schlaug compared professional musicians (who practice at least one hour per day) to amateur musicians and nonmusicians.[38] They found that gray matter (cortex) volume varied in several brain areas involved in playing music, including motor regions such as the anterior superior parietal areas and the inferior temporal areas. The cortex volume in these areas proved to be highest in professional musicians, intermediate in amateur musicians, and lowest in nonmusicians. In addition, research involving musicians who began playing before the age of seven has shown that they have larger and more complex connections between the right and left hemispheres than nonmusicians and those who started playing after the age of seven.[39]

Additionally, the interdisciplinary work of neuropsychologist Allan Schore,[40] who has highlighted the importance of the right hemisphere, seems particularly apt when investigating the synthesis of creativity, play, and neuroaesthetics. As I discussed, much of the research about creative moments of synthesis, illumination, and insight, as well as novelty, unconscious scanning for patterns, and affect regulation indicates the critical involvement of the right hemisphere.

A recent article by psychologist Jerome Singer[41] cites the research of cognitive neuroscientist Jonathan Smallwood and others indicating the involvement of the lateral prefrontal cortex in mind wandering or daydreaming, particularly volitionally.[42] The connections between volitional mind wandering and creative combinatory play would be a very rich and valuable area of further interdisciplinary investigation.

Another fruitful area is that of "mindfulness" research that investigates what I call the incubation stage in both of its forms by studying the effects of meditation on the brain. It would be interesting to see the connections between these states of mind, creativity, aesthetic perception, and play.

As the psychologist Dan Siegel says, "What research findings can be synthesized to suggest and what we propose, in fact, is that an emergent quality of living a vital and flexible life may come from an openness to bilateral functioning involving many ways of knowing…and if this laterality-attachment hypothesis is correct, then a logical implication would be that any experiences that help to develop the processing abilities of the two hemispheres and/or the integrated activities of the two hemispheres may improve certain individual's internal and interpersonal lives."[43]

Conclusion

The incubation stage of the creative process is an intermediate state of consciousness or a state of consciously active reverie in which individuals open themselves to sensory and emotional input from outside and inside themselves, as well as to all information stored in implicit memory. This incubation allows whatever emerges to play in the intermediate space of imagination. We see this kind of marriage between an active discerning intellect and free-floating associative drifting combinatory play in everyday creativity. And we find it is essential to mathematical, scientific, and artistic creativity.

The creative function of imaginative combinatory play involves the ability to discern relations between ideas, objects, feelings, and forms; the ability to see patterns within disparate elements; the ability to see both similarities and differences analogically between elements; and the ability to unite these linkages into new combinations that include asymmetries, contradictions, condensed symbols linked by contiguity, spatial and temporal arrangement, and emotional and narrative meaning.

Far from being a passive, trance-like state, this combination of right-brain dominant reverie and interhemispheric combinatory play is highly active and takes a great deal of discipline and attention on multiple levels simultaneously. It is a way of thinking that includes not thinking and a technique that can be learned and honed, one that is critical to creativity in both art and science.

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