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2. IMPORTANCE OF CREATIVE THINKING FOR PARADIGM SHIFTS THAT FOSTER SCIENTIFIC ADVANCES

There is a strong attraction among scientists, educators, and psychologists to creativity, and this attraction is supported by theories of creativity, theories of intelligence, or education because of current, rapid societal changes, global economic reformation, and technology development that require creative solutions. Because advances in science and technology are likely to affect leadership in industrial productivity, the appeal of creativity for scientists has grown among international competitors.

Scientific advances or scientific discoveries are often mentioned within paradigms. A paradigm represents "a model, template, or matrix for making or evaluating something" (Nickles, 1999, p. 335). A paradigm is a belief system in a field that holds true for a certain time period. However, a paradigm does not remain forever, and paradigms change over time based on conceptual changes in the field. For example, Darwin was born at a time when the creation paradigm was dominant. People, including scientists, believed that God had created all species and the world, so that the universe could not be changed. However, Darwin observed marine fossils thousands of feet above sea level and reasoned that the land had been raised up by earth movements, and he found that the fossil mammals he discovered in South America looked like living mammals from the same area. If each species was created in particular, he questioned why this should be; and he wondered why there were so many species in an island group that looked very similar but with slight differences from island to island. The elegant simplicity of Darwin's observation, reasoning, and questioning guided him to create his evolution theory, which changed the paradigm in science from creation to evolution (Berra, 2008). Scientists call this type of conceptual change a paradigm shift. A paradigm shift means that a new set of rules or standards replace existing rules or beliefs among professionals or within a community. A breakthrough discovery or invention often changes the conceptual framework of a field, and a new accepted conceptual framework leads to a scientific conceptual leap such as the change from creation theory to Darwin's evolution theory. Scientific advances are made from innovative ideas that replace previous understandings; the creativity of scientists plays a critical role for paradigm shifts in science (Nickles, 1999).

How, then, do scientists come up with a new rule, and how do paradigm shifts happen? Originality or novelty is often discussed to explain the cognitive capacities

M. K. Demetrikopoulos & J. L. Pecore (Eds.), Interplay of Creativity and Giftedness in Science, 15–28.

that may contribute to a paradigm shift. So what helps scientists to generate original ideas? Gardner (1983) explained originality within the context of a domain-specific skill that shapes an unfamiliar but worthy product or performance. Originality and novelty are the characteristics associated with creativity, and scientists who want to change a paradigm need to produce new ideas or answers to the questions or discover new things that impact the current conceptual framework. However, scientists cannot produce original thinking like a sudden rain from a blue sky. Clouds should be formed in advance, in order to have rain. Likewise, novelty cannot be accomplished without prior reasoning and thinking in the field of study. Knowledge in the field of study is considered to be a critical element to generating novel ideas, meaning that creative scientists need to acquire a mastery of the knowledge in their research areas (Gardner, 1983). After acquiring knowledge in the field, scientists may formulate adequate problems for scientific discovery, and those discoveries will have an impact on existing understanding.

The possibility of creative solutions in science comes from the investigation of previous sets of beliefs. Scientists need to know how to make inquiries and to look at the existing agreed upon beliefs from different angles in order to answer questions and make scientific advances (Kuhn, 1999). Not every scientist finds appropriate questions from different perspectives, from within the predominant beliefs. Then how are creative scientists capable of asking the right questions and seeing the same things in different ways? The sources of original ideas or the ability to think from different perspectives than the established beliefs are not clearly identified. There have been efforts to discover attributes or strategies for making significant scientific discoveries. With the increased importance of advances in science, it seems clear that having creativity that generates new ideas and seeing things differently is an essential ability in science. The “Aha” moment of accidental discovery has been mentioned throughout scientific history, demonstrating the same importance of creativity in the field of science as exists for poets and artists.

For a better understanding of creativity, many definitions and various approaches have been explored. According to some definitions, creative thinking allows scientists to view things differently from the common understanding of observed phenomena and contribute to scientific advances (Dunbar, 1999). One of the most common ways to investigate scientific creative work is to analyze creative scientists themselves. The characteristics or cognitive styles of creative scientists include elements such as imagination, intuition, insights, and inspirations, which are often examined to learn about the creative strategies the scientists applied (Piirto, 2011). Researchers interested in special scientific ability and creativity have examined creative scientists’ thinking processes and personalities to try to understand the exceptional performances that allowed them to make scientific conceptual leaps (Dunbar, 1999).

When scientific discovery is discussed, note that there are two different kinds: factual discovery and conceptual discovery (Noe, 2001). Kuhn (1999) distinguished these two different discoveries as normal science and scientific revolution. Normal science involves researching within a paradigm and finding pieces for solving a puzzle, but scientific revolution results in a conceptual change in normal scientific research. Revolutionary scientific discovery creates a paradigm shift, producing problem-solving efforts and representations of belief systems affecting common knowledge during certain time periods (Gruber, 1993). Belief systems do not, however, always represent the shared understandings of all community members. While anyone whose experience corresponds to claims made by common knowledge may not have problems with shared generalizations, others whose imagination or understanding of current scientific agreement is not commensurate with prevalent knowledge may be frustrated by these shared beliefs. The frustrated person may attempt to produce a justification or interpretation of a different type of observation or understanding than that of the existing paradigm. Through the process of a new interpretation and inspection of a new assumption, a conventional paradigm can be replaced by a new set of paradigms, and a paradigm shift happens.

In examining how considerable scientific advances have been made, scientists raised questions and investigated problems with different points of view from those of traditional knowledge. Scientists are remarkable for their rational process, but the rational process is not enough to explain the capability of asking original questions to produce breakthrough discoveries. Original questions end up providing new conceptual understandings of problems being worked on. Therefore, as many researchers have explored ways to identify a process of scientific discovery that would create changes in conception to frameworks in a field, creativity has been examined as a factor in scientists' capabilities that go beyond the rational.

To see how closely creative thinking processes are intertwined in scientific advances, creative scientists are often analyzed to examine how they differ and what characteristics allow them to produce extraordinary performances, as well as to find ways of nurturing those characteristics and the role of creativity in scientific discoveries. Common to all creative scientists is that spirit of wondering and questioning that constitutes the creative scientific attitude. For example, Einstein loved asking probing questions with a curious mind. In his autobiography, he stated that:

> For me it is not dubious that our thinking goes on for the most part without use of signs (words) and beyond that to a considerable degree unconsciously. For how, otherwise, should it happen that sometimes we wonder quite spontaneously about some experience? This wondering seems to occur when an experience comes into conflict with a world of concepts which is already sufficiently fixed in us. Whenever such a conflict is experienced hard and intensively it reacts back upon our thought world in a decisive way. The development of this thought world is in a certain sense a continuous flight from wonder. (Robinson, 2005, p. 29)

As shown in his statement, Einstein drove himself into the world of wondering and questioning. He loved intense discussions with his students and colleagues. He also recognized that the Newtonian Laws could not be applied to light. Einstein questioned the idea that time was absolute. If time was absolute, one hour on Earth would be the same as one hour on Mars; however, Einstein imagined himself chasing a beam of light (Banerji, 2006). From his imagination, he understood the nature of light and time, which was only later proven true through mathematics. This was not because Einstein did not have a deep understanding of quantum physics and mathematics, but because his imagination, insight, and intuition guided him to produce innovative thinking. Einstein stressed the importance of imagination and said that "Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand" (Smith, 2003). The traditional procedure in physical science is to make observations first. Then scientists create hypotheses and collect systematic data to explain what they observed. Based on the results of the analysis of the data, scientists develop principles and theories therefrom. However, Einstein started with a higher level of abstraction through imagination first, and then drew empirical inferences and linked to other laws. The thinking process of Einstein was not aligned with the traditional scientific research process. Beyond rational thinking capability, and knowledge, he applied creative thinking strategies to his innovative discovery. Imagination, intuition, insight, enjoyment, and inspiration played essential roles in his innovative thinking. This chapter explores imagination, insight, and intuition, the core fundamental characteristics for creative analogical reasoning and dynamic connections among different cultures and ideas, in order to enable creative leaps in science.

NATURE AND ROLE OF IMAGINATION: HOW IMAGINATION IMPACTS SCIENTIFIC ADVANCES

The Merriam-Webster (1999) dictionary defines imagination as "the act or power of forming a mental image of something not present to the senses or never before wholly perceived in reality." From this definition, imagination is considered as a way of exploration and potential experience beyond what we can perceive. Imagination has been meaningful to all creative people. Psychologists have studied imagination to identify its origin, role, and meaning for their psychological therapies. However, in the field of creativity, imagination is considered a strategy for allowing people to open their minds and get over barriers between reality and thoughts, concepts, ideas, images or whatever we experience. With imagination, creative people may express their thinking more freely in unique ways so that they can produce significant outcomes compared to other people. It is exciting to watch science fiction movies or read science-fiction stories because their imaginings make us think of capabilities beyond reality, and their descriptions are vivid enough to make us think, "What if that story is true?" Many inventions were born out of the imagination. Robert Goddard was captivated by the novel, *War of the Worlds*, and the book evoked his imagination to invent the first liquid-fueled rocket (Strauss, 2012). A science-fiction novel, *Twenty Thousand Leagues Under the Sea*, stimulated Simon Lake, who is the father of the modern submarine, to imagine undersea travel (Strauss, 2012). John Horgan (1996) mentioned in his book, *The End of Science*, that "No matter how far empirical science goes, our imaginations can always go further" (p. 30).

Imagination is sometimes discussed and more highly valued in the fields of art and literature than in science. In the field of business, people have dedicated themselves to improving imagination in order to solve problems in creative ways. However, in more recent times, imagination has also been appreciated in the area of science. Polanyi (1958) addressed the similarity between novel writing and questions of mathematics that can also be applied to science. A theory and hypothesis grow depending on imaginative thinking, empirical findings, and systematic verifications that take a long period of time; in the same way, a novel grows with the author's imagination, research on the settings, and the story synopsis while the writing is occurring. Visualization helps people in both areas, the scientists creating original questions and writers creating original themes and stories that take them beyond what they are seeing in their reality.

Numerous references to the imagination can be found in history. Cocking (1991) identified that Quintilian referred to imagination related to *phantasiai.* A person who is very sensitive to impressions will have the greatest power over emotions, and this power of vivid imagination is presented to the sensitive person in the most realistic manner. Imagination encompasses an elaborate wish for a future arrangement of events, fantasy stories, or daydreaming (Singer, 1999). Affective awakening induces people to imagine what they long for. Barker (1938) recognized that Spinoza identified the imagination as the lowest level of knowledge or cognition; however, imagination provides higher levels of knowledge when it is furnished with distinct and adequate ideas. Creative performances are accomplished through imagination in various forms depending on the discipline. While the process of the imaginative thinking process in the fields of art or literature may be involved with unique and brilliant works, imagination in the field of science inspires creative scientists to wonder and even provides esthetic aspects to their theories. Streminger (1980) examined Hume's theory of imagination and identified that imagination is in the area of subjective abstraction and plays a role in the context of discovery and in the context of justification. A famous example of Kekule's discovery of the molecular structure of benzene may be examined to represent how imagination empowers scientists to build a new concept or an idea. Kekule experienced a daydream in which he imagined the atoms forming into snakelike chains, and then he saw one of the snakes biting its own tail, which made him realize that benzene was a ring-shaped molecule (Weisberg, 2006).

There are many other examples showing the role of imagination in scientific discovery. Isaac Beeckman (1588–1637), who introduced the concept of the compressibility of the lower layers of the atmosphere and the weight and elasticity of the whole mass of air, imagined the air as a large sponge surrounding the earth. Imagination is the power of creating new intellectual conceptions (Webster, 1965).

However, imagination without knowledge in the field of science and without the scientist's intention or will to discover cannot produce a significant output that will contribute to a paradigm shift.

Imagination is seen as a single magical event; however, as Kuhn (1996) pointed out, scientific thinking advances over time. There is a kind of chain feedback of observations, which lead to theories, which in turn lead to a world view. New scientific theories and products start from the imagination and build their foundations step-by-step, over a long period of time, for scientific verification. No single experiment can make a generalization of a new idea. Imagination makes individuals ask "what if" questions and guides them to investigate their questions through observations. The unconscious process is geared up by scientists' intention of what they want to achieve and to believe (Lieberman, 2003; Modell, 2003).

Imagination represents an understanding and insight into the world that is not readily acceptable to others as an important and meaningful experience. Murray (1986) examined Sartre's thought about imagination, and addressed the idea that we always project ourselves toward expected future potentials, and imagination leads the projection. Imagination is the essential part of our life to reach better understanding of knowledge, including in the realm of science. Imagination allows people to envision other courses of action in the real world as well as diverse ranges of responses toward problems; this helps creative people to predict the immediate and long-term future. This is the important role of imagination in scientific thinking (Person, 1995).

Mental capabilities, furnished with desire and knowledge, shape an idea with beauty and meaning. Imagination often allows scientists to come to the limits and exceed the boundaries of the self, of the communicable, and of the sequential (Maguire, 2006) and to go beyond rational understanding. Einstein had special talent for envisioning problems, and he enjoyed fantasizing: "When I examine myself and my methods of thought I come to the conclusion that the gift of fantasy has meant more to me than my talent for absorbing positive knowledge" (Gardner, 1993, p. 105). He enjoyed visualization and imagination to build understanding and inquiries rather than following mental models created by other scientists. For him, imagination was the important thinking strategy, and his enjoyment of exploring worlds within his own mind was a source of his productivity. However, imagination is not the only thing that enables creative scientists to produce significant performance. Even for Einstein, his knowledge, his capacity to integrate empirical phenomena, his rational thinking strategies, and his other creativity characteristics including intuition and insight enabled him to think innovatively.

INTUITION

Everybody has intuition. Intuition is used in daily life to make decisions such as choosing which direction to drive. However, many don't trust their intuition for making important decisions because it cannot be explained using reason or logic.

Intuition is considered knowledge that is beyond logical explanation, like other creative characteristics. Intuition is an immediate understanding of something vague or some kind of natural knowing independent of rational thought. Intuitive thinking is frequently interchanged with the word "hunch," because intuition does not provide proof or analysis for the result of thinking. Usually, rational thinking takes formalized steps to achieve new knowledge, and this knowledge is the extension of what we already know. However, intuition happens in a sudden moment, where one reaches a conclusion or develops insights into a problem (Weisberg, 1993).

Many researchers in the field of creativity and science have taken up the challenge of defining intuition and identifying the intuitive thinking process so that they can understand the role of intuitive thinking in scientific discoveries. Policastro (1999) defined intuition as:

> A tacit form of knowledge that orients decision making in a promising direction. In the context of problem solving, a promising direction is one that leads to potentially effective outcomes. In the context of innovation, a promising direction is one that leads to potentially creative result. (p. 89)

This definition suggests that intuition is a form of knowledge that guides decision making toward creative outputs or performances. As Policastro describes it, intuition enables people to select appropriate information or make proper connections of information from numerous alternatives for decision making. Intuition guides people to explore the most valuable connections of information, and intuition sets boundaries for investigation. In this context, Policastro identifies intuition as a tacit form of knowledge that largely confines the creative search by setting its major scope. However, Policastro's definition does not provide an explanation of how intuition happens.

Some scientists explain the intuitive thinking process using the concept of an intelligent memory. The neuroscientists Gordon and Berger (2003) explained the process of engaging in intuitive thinking with the concept of intelligent memory as:

> Intelligent Memory…is like connecting dots to form a picture. The dots are pieces or ideas, the lines between them are your connections or associations. The lines can coalesce into larger fragments, and these fragments can merge to form a whole thought. This whole thought may be a visual image, a piece of knowledge, and idea, or even a solution to a problem. Individual pieces, the connections, and the mental processing that orchestrates them generally work together so they appear to be a single cognitive event. That's what happens when ideas or concepts "pop" into your mind. (pp. 8–9)

Bowers and his colleagues (1990) examined intuitive judgment and stated that intuitive judgment can be a result of previous logical thinking processes, meaning that intuition is based on intelligence collected from experiences and from previous knowledge. In this regard, intuition may stem from prior knowledge and the logical thinking process rather than being a natural form of knowing. In any case, intuition does not involve conscious determination but comes in the relaxed moment after struggling with a problem. Intuition happens unexpectedly through continuous mental activity and a connection between unconscious awareness and the logical thinking process (Isenman, 1997). Although intuition suggests that a sudden idea is true, the result of intuitive thinking cannot be verified. Intuitive thinking output cannot be accepted as a new scientific discovery or solution to the problem without any verification. Scientists need to change their intuitive assumption to a testable hypothesis in order for experimental results to be accepted among scientists and to contribute to shaping a new paradigm in their field (Eysenck, 1995).

NATURE AND THE ROLE OF INSIGHT

Understanding insight is important for identifying the creative thinking process, so a consistent line of research has tried to understand the process of problem solving including insight. However, insight is difficult to understand, and there is no more clear agreement about how insight occurs than there is with many other creative thinking processes. Several different theories have been proposed to illustrate insight for problem solving. The first view on insight is to consider insight as a mystic power. This approach describes insight as something that can be experienced when unnecessary constraints are relaxed and a new portion of the solution space becomes available for investigation. Sometimes, restructuring of a problem is necessary to solve that problem; however, when a person attempts to solve a problem, that person is fixed to the current experience so that he or she cannot think of alternative ways to see the problem (Jansson & Smith, 1991; Weisberg, 2006). In this viewpoint, insight is the mystic ability of restructuring problems so that creative scientists having insight can accomplish significant problem solving and contribute to scientific advances.

The second approach is to consider insight as the capability to associate different ideas or knowledge. If we assume knowledge as a node in a knowledge graph (Pols, 2002; Schilling, 2005), finding a solution to problems is to discover the correct associations of knowledge nodes. Insight is experienced when an unlikely association of knowledge for solving the problem is retrieved, and this is a result of analytic reasoning. Appropriate study design and analytic reasoning enable people to come up with new paths for solving problems. A capability of strong association of knowledge is the matter of insight (Weisberg, 2006). In this approach, insight into solutions happens with a gradual accumulation of knowledge and experience. Insight is not a mystical power but an analytic reasoning process. Insight is like a growing organism in our minds. Ideas and information undertake recombination as a person experiences and acquires more knowledge. A creative person selects only useful information or ideas for further cognitive processes.

A third approach is to understand insight as a special information process. Insight is a stretched, unconscious leap in thinking, a critically accelerated mental process, or a short-circuiting of the normal reasoning process (Perkins, 1981). A leap in thinking means that someone tries to understand phenomena, but there is a gap between acquired information and the understanding of observed phenomena, and insight fills this gap through an accelerated mental process. In the 1700s, Isaac Newton built a significant intellectual structure with the discovery of the laws of gravity. When he was under the tree watching an apple fall from a tree near him, it suddenly struck him to make a connection between the moon and the apple and to understand that the earth's gravitation must be curving the moon's path in a way resembling the apple's path in falling toward the earth (Gleick, 2003). Insight enabled him to fill in the gap between the apple's falling and moon's path, so that he could understand the inner nature of gravity clearly.

The fourth theory about insight recognizes it as three information processes: selective encoding, selective combination, and selective comparison (Sternberg & Davidson, 1999). The selective encoding process constitutes a separation of relevant information from irrelevant information. A creative person with insight can identify relevant information from a vast store of information in order to solve problems. The selective combination process comprises competency in combining relevant information for problem solving. This competency is an important ability of connecting important information to come up with new pathways to the solution. Currently, the importance of interdisciplinary study has been suggested, and selective combination may be a critical thinking process for creative performance. Finally, selective comparison involves connecting old information to new information in order to understand observed phenomena better and to solve problems.

All of the proposed theories related to insight have strengths and weaknesses, and no theories thoroughly explain how insight happens and what insight is. However, they share several characteristics of insight, demonstrated through science history:

- Insight happens suddenly. In many scientists' experience, a problem is solved in the flash of a moment. Insight takes place suddenly, finding a new direction to the problem or finding connections between separate pieces of knowledge.
- Insight happens when there is no progress after intensive work. However, preparatory work is essential in order to experience insight. Insight does not occur without previous efforts.
- Insight happens after an incubation period. This is the stage in which unusual connections are made. When we try to solve problems consciously, the thinking is done in a logical fashion. However, in the moment of insight, all the pieces of information which seemed to be separate are connected. Sometimes, this is called an "Aha" moment (Weisberg, 2006).
- Insight enables people to see a new approach to the problem (Weisberg, 2006). When a scientist has a question based on his or her observation, the person works on the problem in order to answer the question with in-depth knowledge and reasoning. However, the scientist arrives at a point of not having made any progress in solving the problem. Then, insight occurs allowing a scientist to look at the problem in a different way and from unusual perspectives. Insight helps people to reconceptualize problems to come up with an "Aha" moment.

- Insight helps people make connections between old and new information.
- Insight should be verified in order to create a theory or meaningful knowledge.

Whether insight is an experience beyond acquired knowledge or is a result of previous knowledge and an elaborate study design, insight plays an important role in coming up with significant solutions for creative scientists. Many scientific advances have been made through insight, enabling scientists to achieve a new pathway of thinking to the solutions. Without insight, no matter how new, scientists would slip into confusion.

Although insight guides a scientist to solutions, the solutions or ideas derived from insight cannot be accepted within the professional community without verification. A verification process, after insight occurs, needs to be followed to find out if the connections made through insight make sense. Scientists may go through calculations or experiments to verify whether their possible solutions from insight would work or not. Cskszentmihalyi (1996) suggested four main conditions for this stage. The person who gets an idea to solve a problem through insight should continue to be flexible and open to new ideas. Also, one must keep in mind one's goals and feelings to make sure that the work is processed as intended. The third condition is to acquire updated knowledge in the field in order to make use of new techniques, information, and theories. A deliberate effort to answer a question enables individuals to understand the inner nature of thinking clearly and come up with restructured inquiries. The last condition is to communicate with others involved in similar problems, so that one can focus on the idea and have it accepted by other people in the field. This stage is critical for making a paradigm shift, because it involves the process of changing people's predominant understanding so the idea can be recognized as a new paradigm.

INSPIRATION

Inspiration is the energy that makes creators keep working on the problem and inquiring. Inspiration provides the motivation for scientists to make intentional efforts to keep their minds open. Although it is hard to prove and define the best conditions for creative work, creative people seem to be inspired by their environments. There are many things suggested as inspiring elements for creators. Piirto (2011) listed possible elements that can inspire creators such as love, nature, transcendent experiences like a mysterious force, substances, dreams, travel, the dark side of emotions such as death or illness, other creative works or creators, being thwarted, and a sense of injustice. Some of these inspirations are geared toward artistic creators, but many of them are also related to scientific work.

Scientific advances and the success of scientists do not stem exclusively from the internal operations of the individual mind, but often come from interacting with other minds and cultures that support the creative working process. In the field of creativity, chance has been considered a possible element of creative work.

One example of chance is to be involved in highly professional group work in a field. Meeting mentors, having an opportunity to work in a specific lab, or having connections to a professional network are examples of things that allow the chance for creative work. Certain environments have more intense interactions among professionals and provide more excitement so that people have more opportunities to produce more ideas and get new ideas from others. For example, John Bardeen was the first winner of two Nobel Prizes in the same field. He won his first Nobel Prize in 1956 with two colleagues while he was working at Bell Labs on the invention of the transistor. Then he moved to the University of Illinois, where he became captivated by superconductivity and won another Nobel Prize with two researchers in other universities for a fundamental theory of conventional superconductivity. As Csikszentmihalyi (1996) suggested, if scientists are involved with major research laboratories, journals, departments, institutes, and other professional networks, they tend to have more access to new voices that are heard and appreciated, so that they are inspired to keep working intensively on problems. As another example, Niels Bohr, who contributed to understanding atomic structure and quantum mechanics and received the Nobel Prize in Physics in 1922, liked to develop his ideas through interacting with others and discussing various subjects. His debate and friendship with Einstein became one of the famous stories in physics history, and their interaction inspired developments in science as well as inspiring each other (Segre, 2012).

However, even being involved in professional groups does not always guarantee the production of creative breakthroughs. Current academic systems require many publications and results produced with recognized methodological skills. Researchers must work for grants or publications each year, and it is difficult to get government funding without a specific methodology or specific timelines. As Loehle (1990) pointed out, output pressures and organizational requirements can be barriers to creative production. What if Einstein wrote a proposal for a government funding in order to explore relativity theory? If he specified his method as abstract mathematical thinking in a comfortable chair and asked for funding for 30 years of research, could he get funding? The structure of the academic world may hinder scientists' breakthrough performances, even though professional networking and communication inspire scientists to come up with new ideas.

Because of the significant role of interactions in the field of science, the scientific institutional environment should be designed to build the optimum atmosphere for creative performance. Hollingsworth (2012) recognized the significant role of diversity within scientific institutions on creative performance. Diversity allows a scientist to think in flexible ways and be open to new ideas and perspectives. Communication and interaction among scientists with diverse interests allows them more easily to adapt new perspectives and to facilitate creativity in making improvements. Hollingsworth analyzed the organizational context in which major discoveries occurred or did not occur throughout the twentieth century in Britain, France, Germany, and the United States, and he listed the characteristics of organizational contexts that facilitated the making of major discoveries. The first organizational characteristic supporting major discoveries is to have reasonably high diversity. The second characteristic is to have the capacity to integrate diversity. The third characteristic is to support communication and social integration of scientists from different fields through frequent and intense interaction. The fourth characteristic is to have the capacity to recruit scientists who adopt diversity. The fifth characteristic is to have flexibility and independence in the institutional environment. All of these suggest that the main organizational characteristic supporting major discoveries are diversity and flexibility. Diversity and flexibility are the major factors for breakthrough work in scientific organizations. New ways of thinking emerge when individual scientists have intense interactions with other scientists from different backgrounds. Intense and frequent interactions among scientists with diverse backgrounds allow them to look at new aspects and pathways to solutions.

CONCLUSION

Creativity has been a critical element for revolutionary scientific discoveries that result in paradigm shifts. In the history of science, scientific advances were made through the creative thinking process as well as through rational reasoning. Creativity enables scientists to raise questions about what most people believe about a phenomenon. Imagination enables scientists to think about alternative ways of understanding. Intuition and insight help scientists to make valuable connections between knowledge and ideas from various sources and reach toward new solutions to a problem. Inspiration motivates scientists to sustain energy for intensive work. In this chapter, many aspects of creativity, including imagination, intuition, insight, and inspiration, were examined to identify the roles of creativity in scientific paradigm shifts. Although there are many unanswered questions about the process of creative thinking, it is clear that the creative thinking process helps scientists to fulfill their duty to make sound progress in developing theories and contributing to revolutionary scientific discoveries for new scientific conceptions.

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