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3. TWENTIETH CENTURY SCIENTISTS WHO EXEMPLIFY THE INTERPLAY OF CREATIVITY AND GIFTEDNESS

INTRODUCTION

In the 20th century, innovative scientists made many contributions to our society and well-being, as well as expanded our basic understanding of natural phenomena. Children today study the structure and function of cells, DNA, and the atom using computer simulations and videos at home and at school. In this chapter, we focus on the life histories and accomplishments of three 20th century Nobel Prize-winning scientists to gain an understanding of the factors that may have influenced their interest in science and unlocked their creative potential. In particular, we examine the lives and creative achievements of Luis Walter Alvarez, Barbara McClintock, and Peter Mitchell. Although these eminent scientists were not formally identified as gifted, they can clearly be thought of as highly intelligent by any standard in light of their considerable accomplishments.

Intelligence, Giftedness, and Creativity

Counter to the 20th century phenomenon of emphasizing intelligence in the analytic domain alone, Sternberg (1985) conceptualized intelligence as residing in three domains – the creative, the practical, and the analytic. Intelligence quotient (IQ) tests such as the Stanford-Binet and the Wechsler Intelligence Scales have been used to identify children with above average intellect for advanced and accelerated coursework, especially in mathematics and science. A common critique of such an approach is that many children with high potential in other domains are not identified. Sternberg (2003) noted that individuals with strong creative abilities may not be the ones with the highest IQ scores. Indeed, one scientist, Walter Alvarez, as will be discussed, failed to meet the minimum required IQ score to be a participant in a well-known study on intelligence (Trower, 2009).

Besides superior analytical ability, various definitions of giftedness also include creativity, imagination, inventiveness, and problem-solving (Gagne, 1985; Renzulli, 1978). In school settings, early identification and educational programming are designed to ensure that gifted children develop their analytical and creative abilities and become successful adults. This is especially important as giftedness has also

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been identified as a non-static characteristic; that it may ebb and, sadly, wane over time if not cultivated. Giftedness rarely metamorphoses into genius (Simonton, 2003). Experience, or context, plays an important role in sustaining giftedness and is also considered to be a key element in developing creative abilities.

According to Sternberg and Lubart (1998), conceptions of creativity focus on the ability of the individual to make associations from among existing knowledge to arrive at new questions, ideas, interpretations, or conclusions about what is already known. Creativity is the product of the interactions among multiple components, including both domain-specific (e.g., knowledge and skills) and domain-general (e.g., personality traits) components (Sternberg & Lubart, 1998). With respect to knowledge, an individual's knowledge is central to creativity with a broader knowledge base enabling an individual to make more novel associations. Exploration of diverse interests and engagement with interesting people from other disciplines are among the recommendations to expand the knowledge base of gifted children and thus support the development of their creative tendencies (Epstein, 1996). At the same time, a certain level of structure and predictability is needed in order to not have creativity be diluted by too many stimuli or be stifled by activities that are too narrowly focused. Epstein also recommended that the optimal learning environment for fostering creativity be one that incorporates formal liberal arts instruction balanced by informal opportunities to explore and cultivate individual interests.

Davis (2003) noted that certain personality characteristics are common among highly creative individuals. These characteristics include being original, artistic, independent, motivated, curious, open-minded, and intuitive. Being able to recognize creativity, a sense of humor, an attraction to complexity, and a willingness to take risks are also among personality traits associated with creativity. Furthermore, creative individuals often persist at exploring complex and challenging problems that interest them. They may enjoy spending time alone in order to think about and work on these problems.

Creativity is often automatically associated with the arts and not necessarily with the sciences, especially the so-called "hard" sciences such as biology, physics and chemistry. The commonly held idea about scientific pursuits is that of highly analytical, methodical investigation, omitting the creative element which is so integral to the process. Scientists use creativity when they generate questions and hypotheses as well as design investigations and technology to study these questions and hypotheses (Deboer, 1991). Bickmore (2010), for instance, held that creativity in scientific research has to do with the process by which the researcher is able to more narrowly define a large question or problem by formulating a list of questions that address the parts of the whole, then deciding which of those questions might be more answerable than others. Furthermore, scientists use creativity when they are generating possible explanations for their results. The construction of theories involves much creativity as they are broad explanations that re-frame current thinking about natural phenomena and offer new insights on existing evidence (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002).

The three featured scientists, Alvarez, McClintock, and Mitchell, were selected to represent the various scientific disciplines. Alvarez received the Nobel Prize in Physics in 1968, McClintock received the Nobel Prize in Physiology or Medicine in 1983, and Mitchell received the Nobel Prize in Chemistry in 1978. In addition, we sought to include a diverse sample of scientists. Alvarez was a Hispanic-American man, McClintock was an European-American woman, and Mitchell was a British man. By examining the stories of these scientists, we wished to gain insight into how their creative abilities were developed and manifested in the sciences.

BIOGRAPHIES

Luis Walter Alvarez (1911–1988)

An American experimental physicist, inventor, and professor, "Luis Alvarez was one of the most brilliant and productive experimental physicists of the twentieth century" (Whol, 2007, p. 968). He is perhaps most well known for developing the Alvarez hypothesis to propose an asteroid impact as the cause of the dinosaur extinction event. Other lifetime achievements include his work on the Manhattan Project to develop detonators now standard in the explosives industry and being a recipient of the Collier Trophy for inventing the radar system used to assist in blind landing of airplanes. Among his many accomplishments, Luis Alvarez was awarded the Nobel Prize in 1968 for his contributions to elementary particle physics which included working with hydrogen bubble chambers to photograph particle interactions, developing computerized detectors to measure and analyze the interactions, and discovering new particles and resonance states (Martínez, 2011).

Early years. Born in San Francisco in 1911 to well educated parents, his physician father, Walter C. Alvarez, had much influence in his life. He was homeschooled by his mother through the second grade and skipped the third grade. In his autobiography, Alvarez (1987) credits his father taking him to the San Francisco Pan-American Exposition in 1955 and his fascination with the Machinery Hall exhibits as the beginnings of his lifelong interest in hardware. He spent Saturdays with his father who conducted physiological research at the Hooper Foundation. While young ten-year-old Alvarez did not find his father's work on the exposed stomach and intestines of anesthetized dogs interesting, the electrical equipment in an adjoining room fascinated him.

At the age of eleven, Alvarez's father gave him a *Literary Digest* article describing how to make a crystal radio using a cylindrical ice cream carton, shellacked copper wire, a galena crystal, and a pair of earphones, which they built together. Due to his keen interest in all things mechanical, Alvarez was sent to Polytechnic High School, a vocational training school for students not preparing for college where Alvarez found himself misplaced as one of the few students enrolled in an academic program.

Interestingly, Alvarez was interviewed by Stanford psychologist Lewis Terman for his famous study of the gifted, but was not selected, nor did he qualify for Mensa membership (Trower, 2009). Of note, none of Terman's 1,528 gifted participants received a Nobel Prize. When Alvarez's father was offered a full-time research position at the Mayo Clinic, the family, which included his father, mother Harriet, older sister Gladys, and younger siblings Bob and Bernice, moved to Rochester, Minnesota. Life at Rochester High School was more social and Alvarez began to come out of his shell. He skated every afternoon, played mixed-doubles tennis, and attended dances. While his high-school science courses were adequately taught, Alvarez did not find them particularly interesting.

Alvarez's father hired one of the machinists at the Mayo Clinic to provide private weekend lessons for him and during the summers the young Alvarez worked in the clinic instrument shop. In Rochester, Alvarez and a friend would sneak past security guards to climb towers and buildings and explore the power house. According to Alvarez, "a controlled disrespect for authority is essential to a scientist" because all good experimental scientists have had "an intense curiosity that no Keep Out sign could mute" (Alvarez, 1987, p. 14). He credits his youth for developing a judicious skepticism about authority and regulations.

College years. In 1928, Alvarez entered the University of Chicago where he lettered in gymnastics by practicing two hours a day every day for four years, and pledged Phi Gamma Delta, which became the center of his social life. During his undergraduate years, he lived in the fraternity house. By his junior year, Alvarez found physics, a relatively new science discipline, writing "the physics library was so engrossing that I had to force myself to leave it for food and friends" (Alvarez, 1987, p. 22). According to Alvarez (1987) and supported by Trower (2009), his ability to retain material published in physics journals was excellent. He was readily able to reproduce equations or text from memory, to recall author's names and recall locations of important graphs in an article.

For his first undergraduate research project, Alvarez constructed a Geiger counter with limited known details or the aid of specifications (Alvarez, 1987). The task tested the limits of his skills as he spent countless hours in contented solitude on the project. As an undergraduate, Alvarez learned persistence, found inventing enjoyable, and discovered a passion for optics (Trower, 2009). In 1932, Alvarez enrolled in graduate school at the University of Chicago and moved into the graduate students scientific house, which contained a piano. A fellow housemate was an accomplished musician and taught Alvarez the basics of harmony. As with mathematics, Alvarez discovered that with sustained effort, he eventually could play by ear any music he ever heard (Alvarez, 1987). While in graduate school, Alvraez constructed a cosmic ray telescope using his Geiger counter tubes. At the request of his academic advisor Arthur Compton, Alvarez traveled with his telescope to Mexico City where he spent a month measuring the East-West effect of cosmic rays and making the significant basic physics discovery that primary cosmic rays were positively charged (positrons). This work resulted in a widely referenced paper with Compton putting Alvarez as first author (Alvarez, 1987).

Creative achievements. After completing his Ph.D. in 1936, Alvarez married Geraldine Smithwick, with whom he would have two children, Walter and Jean, and traveled to Radiation Laboratory in California to work with Ernest Lawrence. Upon his arrival, Alvarez learned to operate and repair the cyclotron and was soon challenged by his mentor, Lawrence, with designing the magnet for a new cyclotron. With respect to what helped him become a professional nuclear physicist at Radiation Laboratory, Alvarez (1987) writes of his intense curiosity about how everything works and Lawrence's journal club, a weekly gathering of physicists to discuss the nuclear-physics literature. On the advice of his father, every few months Alvarez would spend an evening with his eyes closed as he tried to think of new problems to solve. His first wonderings were of the problem of slow-neutron capture (i.e., resonance), which led to his invention of time-of-flight techniques to make the first measurement of the magnetic moment of the neutron. Another accomplishment at Radiation Laboratory included include devising a set of experiments to observe K-electron capture in radioactive nuclei as predicted but not observed by beta decay theory, discovering the radioactivity of tritium and measuring its lifetime (Nobelprize.org).

With America's imminent involvement in World War II, Alvarez was dispatched to the Massachusetts Institute of Technology, and a summer in England, to help develop war-fighting technologies (Trower, 2009). There he developed three important radar systems: the microwave early warning system, the Eagle high altitude bombing system, and a blind landing system known as Ground-Controlled Approach (Nobelprize.org). In recognition of this work, Alvarez received the National Aeronautic Association's Collier Trophy. Upon his return from England, Alvarez went to work at Los Alamos on the Manhattan project. There he devised an intelligence gathering system carried on an airplane for monitoring fission products by detecting radioactive gases. When Alvarez arrived at Los Alamos, he became involved with the design of "Fat Man" (a plutonium bomb) since work on "Little Boy" (a uranium bomb) was well developed. His tasks involved finding a way to simultaneously and symmetrically explode the tiles that surround the plutonium pit required to initiate a nuclear explosion (which led to the development of detonators now standard in the explosives industry) and a way to measure the energy of the nuclear bombs. Alvarez flew in the observation plane and deployed the pressure sensor gauges used to measure the bombs energy on both the Trinity, New Mexico test flight and the Hiroshima raid (Alvarez, 1987).

Subsequent to returning to Berkeley in 1946, Alvarez was elected to the National Academy of Sciences on the nomination of his mentor, Ernest Lawrence. In addition to providing technical advice to the U. S. government as an active member of JASON[1], most of Alvarez's post war work involved hydrogen bubble chambers to photograph particle interactions, for which he received his Nobel Prize in 1968.

During this time, Alvarez advised, as an outside director, the newly public Hewlett-Packard Corporation and invented a stroboscopic golf swing analyzer. He also formed Schwem Instruments to commercialize his inventions in stabilized optics and Humphrey Instruments for inventions in virtual optics including a device to automatically determine a person's eyeglass prescription (Trower, 2009, p. 12).

Toward the end of his career, Alvarez applied his talents to solving problems that interested him. He showed that sufficient evidence existed for Oswald to be the single shooter in the J. F. Kennedy assassination (Trower, 2009; Whol, 2007). Perhaps his most joyful achievement was working alongside his son, Walter, to explain "the extraterrestrial boloid explanation of the extinction of the dinosaurs" (Trower, 2009, p. 17) known as the K-T extinction hypothesis.

Barbara McClintock (1902–1992)

A review of Barbara McClintock's biography showcases not only her contributions to the field of cytology but also those personal characteristics and experiences common among creative individuals. At the same time as she grew intellectually through her studies, she developed other interests such as sports, outdoor activities, and music – all with the encouragement and support of her parents. McClintock valued her time alone, enjoyed thinking about alternative solutions to problems, and was able to retain a sense of humility about her own achievements with a willingness to pass credit for them to others.

Early years. Barbara McClintock was born on June 16, 1902 to Dr. Thomas Henry McClintock and Sara Handy McClintock in Hartford, Connecticut. Thomas and Sara initially named their third daughter, Eleanor, a delicate and feminine sounding name (Keller, 1983, p. 20). However, they changed the baby's name to the more masculine Barbara at the age of four months after observing her temperament to be quite stoic. The new baby did not cry for anything and was content to be left alone.

In 1908, the family moved to Brooklyn, New York where McClintock grew into an independent yet active child. She often preferred to simply sit alone and think, read, or take long solitary walks. In accordance with their approach to parenting, Sara and Thomas supported and encouraged their daughter's differences in personality and interests. McClintock was allowed to play as she wished, and was not made to play with girls' toys which held little interest for her. When she asked for tools at age five, her father gave her a set of toy tools. Furthermore, Sara and Thomas gave much credence to their daughter's preferences regarding her activities. They provided her with the proper clothes for exploring the outdoors and playing outdoor sports of all kinds. When interviewed about her childhood, McClintock recalled, "I could do anything I wanted. I could play baseball, I could play football, I could climb trees, I could just have a completely free time that my brother and the people on the block had" (Keller, 1983, p. 24). Her parents even allowed her to stay home from school for days or weeks at a time to do the things she enjoyed most such as ice skating. They saw school as just one part of their children's lives, and believed that it should not minimize other opportunities for exploration and learning.

Like her older sisters, McClintock was an exceptional student at Erasmus Hall High School. Unlike her sisters, she loved learning and became absorbed in finding novel approaches for solving difficult problems in her science and mathematics classes. McClintock was thus committed to the idea of attending Cornell University to study science when she graduated a semester early at the beginning of 1918. Her mother, however, believed that a college education was not appropriate for women, and refused to support her desire to continue her education. She feared that McClintock might become a female professor, would not marry, and would have no place in society (Keller, 1983, p. 27). In addition, the family was struggling financially and there was no money for college tuition. At the time, McClintock's father was serving overseas as a military doctor in World War I. When her father returned home in the summer of 1918, he was able to convince her mother to allow her to attend college.

College years. In the fall of 1918, McClintock entered the College of Agriculture at Cornell University where tuition was fortunately free. She threw herself into her studies, taking an overload of courses many semesters. In her first two years, she studied a wide array of sciences including botany, zoology, and geology. She also studied music and showed a flare for composition that surprised her harmony professor. She played in a jazz band in her free time. In her junior year, McClintock enrolled in courses in genetics and cytology. At the end of the genetics course, the professor, C.B. Hutchinson, invited her to take the graduate course in genetics which set her on the path towards becoming a geneticist. In her autobiographical statement for the Nobel Prize, McClintock stated,

> By the time of graduation, I had no doubts about the direction I wished to follow for an advanced degree. It would involve chromosomes and their genetic content and expressions, in short, cytogenetics. This field had just begun to reveal its potentials. I have pursued it ever since and with as much pleasure over the years as I had experienced in my undergraduate days. (Nobel Media AB, 2014)

In 1923, McClintock graduated from Cornell University with a Bachelor of Science in Agriculture. She immediately registered as a graduate student, declaring a major of cytology and a minor in genetics. Her thesis advisor was Lester Sharp, a cytologist. He provided her with additional training in cytological techniques, and allowed her to determine the focus of her own research. In 1924, L.F. Randolph, a recent student of Sharp's, hired McClintock who was only in the second year of her graduate studies to assist him with a study of maize chromosomes (Kass, 2003). McClintock was able to refine a technique for effectively examining individual maize chromosomes in a matter of days, accomplishing what Randolph could not in years of work (Keller, 1983). Together they used this refined technique to examine the chromosomes of a unique maize plant that McClintock had located in the Cornell corn fields. They discovered that the plant was triploid; it possessed three sets of chromosomes instead of two (Randolph & McClintock, 1926). McClintock continued the study of the triploid maize plant's chromosomes in her dissertation entitled "A Cytological and Genetical Study of Triploid Maize" (McClintock, 1927). Shortly thereafter, she refined the technique further and was able to clearly distinguish among the ten chromosomes of the maize plant for the first time (McClintock, 1929).

Creative achievements. In addition to the innovations she developed to establish the cytology of maize, McClintock similarly developed techniques for identifying the seven chromosomes of the bread mold *Neurospora* in 1944. At the time, she was a researcher at the Department of Genetics of the Carnegie Institution of Washington at Cold Spring Harbor in New York. Her colleague and friend, George Beadle, invited Barbara to Stanford University in California to solve a problem that was holding back his own research, the behavior of the chromosomes of *Neurospora* during meiosis. The chromosomes were so small that no one had even been able to determine their number, let alone how they underwent meiosis.

At first, McClintock had her own doubts that she would be able to solve the challenge. Indeed, five days into her studies, she was so frustrated that she felt the need to go outside and sit under some eucalyptus trees to cry and do "very intense, subconscious thinking" (Keller, 1983, p. 115). A short half hour later, she had the solution and was able to modify her techniques developed with maize to prepare slides that clearly showed the full complement of *Neurospora* chromosomes (Perkins, 1992). Over the next week, she was able to distinguish among the chromosomes and examine their actions during meiosis. Furthermore, in an interview she recalled being able to imagine herself inside of the nucleus with the chromosomes,

> …when I was really working with them, I wasn't outside, I was down there. I was part of the system. I was right down there with them, and everything got big. I even was able to see the internal parts of the chromosomes. (Keller, 1983, p. 117)

Beadle later wrote, "Barbara, in two months in Stanford, did more to clean up the cytology of *Neurospora* than all other cytological geneticists had done in all previous time on all forms of mold" (as cited in Keller, 1983). Besides her ability to develop new cytological techniques, this example points to McClintock's supreme ability to integrate her past experiences and observations of meiotic chromosomes in maize towards analyzing the behavior of unfamiliar chromosomes.

McClintock's 1983 Nobel Prize in Medicine was awarded for her discovery of transposition, or "jumping genes," in maize in the mid-1940s. Plausible explanations are offered by Keller (1983) and Comfort (2008) among others as to why this discovery was so slow to be recognized by the scientific community. In an interview, McClintock acknowledged, "Transposition was absolutely nonsensical to biologists then" (Keller, 1983). Biologists of this era were convinced that the genes were fixed in their position on chromosomes like beads on a string. In contrast, McClintock asserted the revolutionary claim that genes were able to detach from and reinsert themselves into chromosomes, which regulated the function of other genes. She inferred this from single-handedly performing, analyzing, and synthesizing observations and cytological studies of a unique variegated maize plant over six years. When asked about how she was able to persist at this endeavor for so long, McClintock stated in an interview,

> It never occurred to me that there was going to be any stumbling block. Not that I had the answer, but [I had] the joy of going at it. When you have that joy, you do the right experiments. You let the material tell you where to go, and it tells you at every step what the next has to be because you're integrating with an overall brand new pattern in mind. You're not following an old one; you are convinced of a new one. And you let everything you do focus on that. You can't help it, because it all integrates. (Keller, 1983, p. 125)

McClintock was taken aback when she realized her contemporaries did not understand her reasoning and even doubted her sanity at symposium presentations in 1951 and 1956 (Keller, 1983). After all, she had been elected to the National Academy of Sciences in 1944, and served as the president of the Genetics Society of America in 1945. She eventually decided to largely withdraw from the scientific community that had rebuffed her, but to continue her research on transposition and gene regulation at Cold Spring Harbor. After publishing a 1961 paper drawing comparisons between her work and the work of Jacques Monod and Francois Jacob on bacterial gene control (McClintock, 1961), she only reported her findings in the Cold Spring Harbor annual reports and attended few professional meetings in her discipline prior to receiving the Nobel Prize (Keller, 1983; McClintock, 1987). McClintock's early realization that transposition was a common phenomenon in all sorts of organisms was not widely recognized by biologists until the late 1970s.

Peter Dennis Mitchell (1920–1992)

Arguably the highest honor awarded to Peter Mitchell was the Nobel Prize for chemistry in 1978. His chemiosmotic theory about energy conversion in mitochondria, which was initially rebuffed and criticized by the scientific establishment, came after years of development and modification based on the very criticisms of those who rejected it.

Early years. Peter Mitchell was born in 1920 to a middle class family in England. According to his biographers Prebble and Weber (2003), his upbringing was largely without any noteworthy traumatic events, apart from the continuously deteriorating relationship between his parents. Mitchell benefited from the cultural influence of his mother who ensured that he was exposed to music and the arts. From his father, who was mathematically inclined and university educated, Mitchell seems to have acquired a similar inclination. His childhood interest in cobbling together bits and pieces found outside and around his home into mechanical devices would continue throughout his life. Mitchell engaged in many hours of creating simple experiments at home which was encouraged by his mother with whom he was considerably closer than with his father. His paternal grandparents were modestly wealthy and ran a relatively formal home, making family visits there less enjoyable for young Peter than visits to his maternal grandparents whose middle class home environment was more relaxed and comfortable albeit less luxurious.

With the exception of studying mathematics, Mitchell preferred being at his workshop at home to attending school. His parents' marriage steadily deteriorated over the years and Mitchell and his brother were sent to boarding school in an effort to remove them from the tension and stress of the family home.

He was sent to Queens College, Taunton, in 1931 to study engineering or science. In addition to education, it was intended that the boys learn upper class manners and speech/language patterns. Headmaster Wiseman became a father figure to replace Mitchell's own absentee father and became very influential in Mitchell's life by fostering an ongoing love for music as well as mathematics. Wiseman arranged for him to have a workshop on campus so that Mitchell could spend free time applying the math and science he was learning to his gadgets and creations. Mitchell also became an activist against the hazing that had been traditional at Queens Collegeand succeeded in having it abolished. His social conscience and activism contribute to his broad range of interests beyond the workshop and the laboratory. Mitchell was not especially interested in competitive, team sports, having a propensity for more solitary activities; however, he was encouraged by a teacher and athletic coach to pursue rugby in order to not show fear to his classmates. Mitchell went on to be captain of the team.

While he excelled in math and science, his academic record in the humanities was not stellar. His complaint about history, for example, was that it only focused on wars and battles and that Newton was nowhere to be found. Mitchell did, however, have an interest in certain areas of literature, especially poetry and Shakespeare, having played the part of Macbeth in a school production.

In general, Mitchell reported that his greatest interest lay in arriving at solutions to problems or questions by beginning with first principles and avoiding textbooks. His experience with creating physical objects – his "devices"— transferred to his experience with learning in general. Interestingly, the subject which interested him least among the sciences was chemistry which he described as being taught in isolation from other subjects and to be a string of facts and experiments that were not well related to one another or to anything else.

College years. Although Mitchell was initially rejected due to his performance on his scholarship admission examination, he began his university studies at Cambridge in 1939 upon the strong recommendation of the ever supportive Wiseman. Mitchell pursued his studies in the sciences at the same time that he continued to be very involved with the arts, especially with music. In addition to already being able to play the violin, Mitchell taught himself to play the piano. He preferred the company of artists during these years to that of his fellow scientists and had a reputation for flamboyant dress and non-traditional appearance including the unusual length of his hair for the times. In spite of his colorful and extravagant appearance, Mitchell was a diligent and committed student of science, having been especially inspired by instructors who were able to conceptualize and communicate their subjects as operating within a greater context. Mitchell became a member of the very selective Cambridge natural sciences club and one of his presentations there was on the topic of "meaning," exploring the relationship between principles of biological science and philosophical concerns.

What Mitchell found most stimulating about the department of biochemistry at Cambridge was that he objected to many of the views expressed there, spurring him on to pursue his own investigations and to formulate the beginnings of his own views and theories. He did not distinguish himself during his years at Cambridge, which extended beyond his undergraduate experience through to his doctoral studies. Although his first doctoral thesis was rejected, Mitchell went on to complete the degree and obtained a teaching and research position. Mitchell subsequently moved to the University of Edinburgh and his research steadily proceeded toward the ultimate formulation of his chemiosmotic theory, moving through various barriers and deflections necessitated by external demands for research funding.

Creative achievements. In 1961, he and his wife purchased a manorly "fixer-upper" – Glynn House in Cornwall – which not only served as their residence but also as his new laboratory independent of an university and the attendant demands. Establishing a private research institute was made possible using Mitchell's own funds as well as those donated by his brother. It was here that Mitchell conducted the research which was to result in the formulation of his theory for which he was ultimately awarded the Nobel Prize for chemistry.

In his later years, Mitchell's focus turned to broader concerns about how science and research could or would best serve the greater good and how perspectives of the scientific community were shaped. He became interested in behavioral research and in the well-being of the research community within higher education institutions – the very environment which he had abandoned many years previously. Mitchell especially did not support what he perceived to be a centralization of the direction of scientific research, believing that too much planning would result in stultification of creativity among researchers. In Mitchell's own words:

> We don't do science because we are scientists, because of science—we do it because we are human beings. It is a most wonderful romantic, cultural activity, just as much as being a sculptor. It's problem solving.

Mitchell died in 1992. His passion for an array of interests and disciplines fostered the creativity and commitment that made his accomplishments possible. Mitchell's life work was an on ongoing synthesis of his deep interest in philosophy, social issues, the arts, and science. Although he did not excel academically in subjects outside of mathematics and the sciences, he pursued what educators today promote as "lifelong learning" in the humanities. He was equally a participant and a connoisseur of music; he also learned glass-blowing so that he could create laboratory equipment and build models to support his theories. He often espoused the importance of imagination in scientific endeavors and believed strongly that centralized planning of research would be detrimental.

In addition, Mitchell's dedication to the private research facility he founded and administered stands as tribute to his entrepreneurial skills. At the same time that he engaged in research that would result in the Nobel Prize, he created a financial foundation which supported the Glynn research laboratory for many years.

DISCUSSION / FINAL THOUGHTS

An analysis of the life histories and creative achievements of these three renowned scientists provides insights into how creativity both ignited and sustained their interest not only in science, but also in other disciplines and activities. Alvarez, McClintock, and Mitchell were all attracted to tinkering as children, to building devices, and to problem-solving in their early years. As posited by Davis (2003) and Simonton (2003), context and experience are critical elements in promoting creativity. A consideration of the family context of the three highlighted scientists points to an experience of being encouraged to be an independent thinker and to undertake activities that nurtured their imagination and curiosity. Each of the families was at least of middle class socioeconomic status, affording their children opportunities for education and advancement that would not necessarily be available otherwise. However, the salient feature of these parental influences is that of shaping attitude and encouraging a wide range of interests in their children.

Indeed, Simonton (2003) asserted that "all of the diverse components of exceptional achievement–intellect, motivation, personality, developmental experiences, education, etc.—are multiplied together rather than merely added" (p. 361). The family experiences of Alvarez, McClintock, and Mitchell as well as their educative experiences (Dewey, 1938) thus served to shape their creative potential. These scientists' mentors, teachers, or parents afforded flexibility in their educational and training opportunities providing challenges and allowing them to develop expertise in areas of interest that were later essential for their creative achievements. In the case of McClintock, her graduate advisor provided her with additional training to hone her skills in cytology. Mitchell's headmaster arranged a workshop for Mitchell to use to construct mechanical and electrical devices, allowing him to discover foundational principles in the physical sciences. Alvarez's father similarly arranged mechanics lessons for him and found him summer work in the clinic instrument shop, both of which allowed him to gain skill and confidence in building complex machines and instruments.

Alvarez, McClintock, and Mitchell showed evidence of diverse talents and creative thinking outside of science. Their stories all include participation in sports and an affinity for time spent alone. Alvarez was a gymnast, McClintock ice skated and played sports of all kinds, and Mitchell was the captain of his rugby team. In addition, they all shared a passion for music and played various instruments with great musicality. This musical interest and ability can be seen as an ideal counterpart to scientific endeavors affording each scientist the opportunity to activate a different aspect of their imagination and affective experience, playing perfectly into the advice given by Epstein (1996) to engage in activities that stimulate new kinds of thinking.

As university students, Alvarez, McClintock, and Mitchell discovered science as offering many creative challenges. They pursued challenges in their respective fields unswervingly, and as a result, advanced the understanding of fundamental scientific processes in their respective fields. These individuals described becoming absorbed in their research, and experiencing joy when they immersed themselves in solving a question or problem. Furthermore, McClintock's story includes a specific report of her ability to understand a problem once she had stepped away from it, putting some physical distance between herself and the matter at hand. Reports of creative moments often include this aspect of inspiration when not immediately involved with the problem. Even when faced with extreme resistance to their ideas, Alvarez, McClintock, and Mitchell were undeterred and continued to pursue their research. Their persistence in finding answers to their questions in spite of external discouragements is another feature of creativity which their accomplishments epitomize.

What is absent from these stories may be as important as what is found in them. There is a decided lack of rigidity in their attitude, of needing their environment to be neatly described and organized. There is an absence of a need for control even of their own experimental endeavors in the sense that they were highly collaborative individuals who even welcomed their critics and used the criticisms to improve their work. In fact, Alvarez was reluctant to be listed as coauthor on publications when collaborators contributed a greater portion of the effort, a practice that could have cost him the Nobel prize. Such a lack of personal ego may likely be the result of the broad experience of their lives, of their ability, for example, to become good at playing a musical instrument which requires much practice after many mistakes. That feature of creativity which is openmindedness requires a level of humility which by its very nature does not allow for an overdeveloped ego.

The richness of experience seen in the stories presented here reaffirms what researchers in the field of giftedness, intelligence, and creativity suspect – the role of the environment must be emphasized as educators seek to foster creativity in their students. The "budding scientist" may well fall by the wayside absent someone – family, teachers, and community leaders – deliberately providing context and experience upon which she or he may develop creatively.

NOTE

1 The JASON society brought together the most prominent physicists to consult for the United States government on scientific questions.

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