Play as the Learning Medium for Future Scientists, Mathematicians, and Engineers

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In recent years, playful methods of learning have almost disappeared from school classrooms, and active, creative, extended playtimes during recess, at home, and in neighborhoods have also greatly diminished. This disappearance of play is especially unfortunate because it is happening at the very time that professionals in many scientific, mathematical, and engineering fields articulate the need for creative and innovative thinkers in their professions and advocate for the use of playful learning methods to assist students in developing the intellectual abilities required for excellence in these fields. This article discusses the importance of returning educators' attention to play as the learning medium that can best develop these abilities and motivate students to pursue careers in science and mathematics.

Long ago, sociologist Johan Huizinga suggested that an appropriate way to characterize the human species was with the term *Homo ludens* (man the player) because, as he asserted, "civilization arises and unfolds in and as play."[1] One of the mysteries that theorists and researchers have pondered, however, is why playfulness so characterizes the human species. Most recognize play as the primary medium for learning for young children, of course, but play pervades the whole of human life. Recent brain research has suggested that the playfulness of a species relates to the brain's proportion of body size; that is, the larger the proportion of the body devoted to the brain, the more playful the species and the longer the period in which the species plays.[2] Proportionally, of course, humans have a large brain size, making play important for humans at all ages. Even older adults often keep their thinking and life skills sharper through play.

According to Michael Ellis, play has been important throughout human existence because it serves as a primary adaptive mechanism that has allowed humans not only to survive but to flourish on this planet. He asserts that in play, "Humans are most human. They learn to extend the limits of human experience and to develop the capability to deal with the unknown."[3] Human beings live in unpredictable, constantly changing environments. Throughout the centuries, their capacity for play has enabled them to invent a proliferation of ideas, products, and behaviors that have served both as change adapters and as change agents. Currently, the processes of change in human society seem to be accelerating at an ever faster rate. Almost daily, the news outlets announce recently invented or redesigned products, rapidly occurring social and political events, and newly discovered or developed scientific ideas. Thus, we need to develop our capabilities for the adaptability that playfulness offers us.

Essential Qualities of Play and Playfulness

Researchers and theorists focused on children's play have long agreed on the qualities that make an action playful.[4] Most importantly, they say play must be enjoyable! If an activity does not provide some element of fun, it definitely is not play. Other clear elements that must be present are those identified by Eva A. Neumann: internal control, internal motivation, and internal reality.[5] If players choose an activity, if they actively engage in it, and if they can shape that activity to fit their experiences, then the activity has most of the qualities of play. In contrast, if others control all aspects of an activity, if the choice of engaging in the activity rests with others, and if the activity must be executed in a completely "realistic" way defined by others, then it has none of the qualities of play. Those engaging in such an activity experience it as the extreme of repetitive, tedious work.[6] Even young children, when interviewed, use these criteria to differentiate between activities that are play and ones that are work.[7]

Robyn M. Holmes and Christine J. Geiger have defined playfulness as an internal state, "a predisposition to be playful," and many researchers have studied its relationship to creativity and innovation.[8] Lynn A. Barnett identified five components of playfulness: cognitive spontaneity, physical spontaneity, social spontaneity, manifest joy, and a sense of humor.[9] Barnett and her colleague D. A. Kleiber found relationships between playfulness, verbal intelligence, and creativity in preschoolers. They also found that for girls, divergent thinking was related to their playfulness in pretense.[10] Holmes and Geiger also looked at the relationship between creativity, cognitive abilities, and playfulness, and they found that cognitive spontaneity related to more detailed and imaginative features in drawings but that physical spontaneity related to the number of buildings and the number of different buildings constructed by children.[11] Playfulness appears to provide a predisposition toward certain types of creative acts, including those needed in scientific and mathematical fields.

The Need for Play and Playfulness in Present Scientific Fields

Some periods in history, more than others, have valued the playful nature of humans. Huizinga believed that the Renaissance was an especially playful period "when scientific thought and method showed unmistakable play-characteristics."[12] He considered modern science, that is, the science of the twentieth century, less playful. Today, writers who predict the future stress that humans will need all their playful capacities to deal with the challenges ahead. For example, outlining the challenges of the twenty-first century for the journal of the World Future Society, James Martin suggests that cultivating creativity will be especially important in facing the numerous problems the next generation will have to solve. "The technology of the near future," he writes, "will lead to an era of extreme creativity. Young people everywhere should participate in the excitement of this creativity."[13] Such views are becoming typical of future-oriented thinkers and writers in scientific, mathematical, and engineering fields. Typically, too, they suggest that human progress requires a strong capacity for playful thought and action, one which will foster creative adaptation to change. Clearly, many see playful thought as a powerful requirement for a human species that needs to be able to adapt effectively to changing conditions. It is important to understand how play enhances this adaptability and acts as the medium for learning and creative development. Its value in schools, homes, neighborhoods, and society will then be more greatly appreciated and its varied expressions more often fostered.

Play as the Medium for Learning and Creative Development

In an early publication on play, I asserted that play can be defined as the "medium" for learning at all ages because many qualities of play enhance learning processes. As I wrote then: "All human beings are active seekers of knowledge, and play is an integral facet of this ongoing quest. The pedagogical value of play does not lie in its use as a way to teach children a specific set of skills through structured activities called 'play.' Rather, play is valuable for children primarily because it is a *medium* for development and learning."[14]

Play serves as a medium in six ways, as the latter term is defined in the online edition of the *Merriam-Webster Dictionary*:[15]

1. It is a channel or system of communication, information, or entertainment.
2. It is a mode of artistic expression or communication.
3. It is a means of effecting or conveying something.
4. It is a surrounding or enveloping substance.
5. It is a means of transmitting a force or producing an effect.
6. It is an environment in which an organism can function and flourish.

I applied each meaning of medium to play and developed these relationships:

1. Play serves as a channel of communication for children who are not always articulate in other ways.
2. Play enables them to examine materials and try techniques in artistic and creative endeavors.
3. Play helps them convey ideas and accomplish goals before their language skills are fully developed.
4. Play "substance" provides a filter that allows them to take risks without concern for world realities.
5. Play allows them to feel powerful in transmitting forceful ideas and producing exciting effects.
6. Play promotes an optimum learning environment within which they can function and flourish naturally.

Studies of young children's play have explored the connections between pretend play and creativity; creative problem solving has also been discussed in relation to construction play and games with rules. While there are fewer research studies of older children, the existing research gives evidence of the extensive, elaborate play of children of middle-school years.[16] All of these types of play can have a role in preparing children for scientifically creative adult roles.

Pretense, Fantasy, and Imagination

Jerome and Dorothy Singer have amassed a body of work that shows strong relationships between fantasy and imagination and early pretend play. They state, “Fantasy and imagination are two of the most powerful components of human experience.”[17] The ability to create images begins in infancy and develops into full-blown fantasy pretense by preschool age. The Singers found that older children still draw greatly on fantasy, but their play is more likely to be private or focused on technological media. They state that such imaginative experiences may reach their peak in adolescence, when young people explore their “possible futures and possible selves.”[18] Other research also has supported the importance of the links between imaginative play and creativity. In a review of studies of pretense and creativity, Eleni Mellou examined the particular aspects of pretense that seemed to relate to creative thought and found that, in this type of play, children perform transformational operations on their roles, objects, and themes.[19] Practice in using transformational operations appears to be closely linked to creative thought, which supports a major principle of Jean Piaget that play can be a vehicle for constructing logico-mathematical knowledge.[20] The connection between transformational operations and creative thought also supports Lev S. Vygotsky’s view of the importance of co-constructed pretense in furthering thought development and self-regulation.[21] According to Doris P. Fromberg, young children’s sociodramatic play provides an important vehicle for making meaning because it includes aspects of script theory (understanding implicit rules), theory of mind (understanding the thoughts of others), and metacognition (understanding ones’ own thought processes). Fromberg asserts that together these form a dynamic system that involves phase transitions, which result in “meaningful, extended, and expanded development for children.”[22]

In a study of college students’ remembrance of their childhood play, Doris Bergen and Elizabeth Williams found that most young adults recalled salient play experiences from the period of their lives when they were eight- to twelve-years-old.[23] Much of their reported play involved elaborate, long-duration imaginary worlds they concocted in bedrooms, basements, and other private spaces. In these worlds, they either played the roles themselves or used small-scale objects (action figures, cars, dolls) as the protagonists. These play experiences resembled the kind of *worldplay,* involving extended periods of elaborate pretense with scripted events, dynamic actions, and detailed settings and scenery, similar to that reported by the recipients of the MacArthur Foundation "genius" awards studied by Michelle and Robert Root-Bernstein. The Root-Bernsteins found that many MacArthur fellows, honored for their creative work as adults, reported engaging in extensive imaginary worldplay in their childhood.[24] Interestingly, both the scientists and the artists in the sample reported that worldplay was a prevalent activity in childhood. The fellows also saw their play as having relevance for their adult work. As one of the scientists in the study said, "It is necessary to imagine what needs to be discovered before discovery can be made."

The Root-Bernsteins found, however, that the college students they asked about the importance of their childhood worldplay differed from the MacArthur fellows. While the fellows valued the long-term effects of their early play, most of the young people in training for science fields failed to see the relevance of their worldplay to their scientific careers. The Root-Bernsteins speculate that "students of science in general are not adequately introduced to the imaginative or playful aspects of their discipline and may therefore underestimate the creativity needed to succeed in it." The researchers' study of early worldplay has led them to note five ways in which child worldplay affects adult creativity: (1) exercising their imaginative capacities such as imaging, empathizing, and modeling—all tools for thinking; (2) increasing their capacity to continue imaginative play into later ages—using small-scale or imaginary settings; (3) enhancing their problem-solving skills—both in fantasy and in real life; (4) testing their daring and rule-breaking or rule-making abilities and relating those to real-world problem solving; and (5) bridging the gap between their virtual (personal) and their creative (societal) imagination.

Construction Play and Creativity

In a discussion of construction play, George Forman asserts that such play is not "acting to make something happen" but rather "acting to see if something might happen."[25] That is, children experiment with building objects in order to learn more about the physical world and the laws that operate in the world. Higher-level thinking occurs when they attempt to solve problems that the construction materials (wood, clay, metal, and paper, for example) pose because the solution requires divergent rather than convergent thinking. Their constructions are really designs involving dynamic systems. All the scientific and mathematical professions value this type of systems thinking. Construction play can involve either actual objects or virtual objects and occurs in many types of computer play, such as simple programming or problem solving.[26] Forman asserts, "Not only does such a medium provide children with a rich problem solving environment, it also embodies computational thinking. . . ."[27] Adults who have gone into scientific, mathematical, and engineering fields were often great construction players as children. The most famous of these may be architect Frank Lloyd Wright whose extensive childhood block-building experiences reflect his later architectural designs.[28] The Root-Bernsteins point out that writer H. G. Wells modeled wars in miniature when he was young and continued to do so into his later years.[29] According to Sheila J. Henderson, who studied the lives of inventors, during childhood these individuals "had the opportunity to participate in activities based on active, problem-based discovery learning in early school years up through graduate education."[30] In a study of creative innovation, Joseph Anderson discusses the advantage of a playful approach to innovation by comparing work and play. He describes work as tiring while play energizes, gives direction, and helps to focus activity. Thus, he concludes that innovative work is really a type of play.[31]

The "worlds" children construct, either with concrete materials such as blocks or interlocking pieces or with virtual-reality simulation games, give them the imaginative experiences and the interest in "seeing what might happen" to prepare them to create new worlds of design in later work experiences. Yasmin B. Kafai says that technology often provides experiences that include all three major types of play: practice, pretense, and games with rules.[32] Research in many fields of science and mathematics now involve the mapping of data into communication networks and system models with the aid of computers. Kafai and her colleagues have indicated that play theory has implications for computer-design theory, especially in relation to the design of computer toys.[33] One inventor discussed by the Root-Bernsteins, Jerome Lemelson, has over five hundred patents related to robotics, computer vision, the VCR, camcorder, and fax machine. His first two patents, however, were for toys.[34]

Games with Rules and Innovation

Piaget's descriptions of children's play with marbles show many instances of how children invent or adapt rules to enable play to go more smoothly, to be fairer, and also to be more fun.[35] Rheta DeVries, who has studied game playing in young children extensively, indicates that two of Piaget's stages—incipient cooperation and codification of rules—are evident in many children's games as they learn to develop and modify the rules. These negotiations and innovations regarding the game enable the playing of it to continue and to be more equitable. Thus, she says that games with rules reflect both intellectual and sociomoral development.[36] In particular, children who play games in which they design or adapt rules use a wider range of strategies and negotiate differences more effectively. They are also better able to understand the perspective of others. All of these abilities are essential for creative problem solving in teamwork situations, an aspect important in most professions, where creative solutions to problems often involve negotiation, good listening skills, and the ability to adapt ideas from varied sources. Many of the college students in Bergen and Williams' study reported that their favorite play was some version of a "game with rules," often played in the street, a park, or backyard, and usually away from adult supervision.[37] Such games differ from sports because the rules are child generated and continually revised during play. This type of play often also has an imaginative and/or a risk-taking element, in which the rules are changed and made more difficult in order to take the game to more challenging levels. The Root-Bernsteins write that Alexander Fleming, the discoverer of penicillin, liked to change the rules of games to make them more difficult because that made the game more fun. According to them, "Everyone who knew Fleming knew he liked to play."[38]

Conditions for Playful Thought

For playful thought to flourish in adults, conditions must be present that are similar to those essential in children's play. For example, at any age, for an activity to be play, it must have some elements of choice and self-control. Of course, there are many playful activities that have some constraints, but if individuals have little or no ability to control their actions, to bend external reality, or to experience internal motivation for doing the activity, they will be less likely to label the activity playful. When adults play with ideas, use creative techniques, accomplish risky or unusual feats, employ models to exemplify their mental worlds, and allow themselves to be truly comfortable and creative in their environment, they are also using the medium of play, although they may call it something else. In a discussion of science-based innovation, Alexander Styhre compares play and the concept of "flow" that Mihaly Csikszentmihalyi has identified as vital to creative work.[39] Styhre states, "Even though play and flow are not synonymous, flow and the sense of full control is what is central to successful playing: it is a sense of being in full control while conducting a specific task one is qualified and skilled for."[40]

Translating the Elements of Play to Science, Mathematics, and Engineering

Writers who address the need for creative thought in science, mathematics, and engineering are beginning to discuss how these elements of play can be translated into the preparation of professionals who will engage in playful, creative thinking in their fields. For example, in a discussion of the optimum preparation of scientists, Margery D. Osborne and David J. Brady assert, "Learning is a component of playing, and playing is a component of learning, and both taken together constitute a process of coming to know. They are aspects of one epistemology," and they suggest that a richer understanding of science can be obtained through play.[41] In an article describing the playful language used by mathematicians, Abhijit Mehta agrees, noting that mathematicians and physicists often take common words and use them to describe complex things. Mehta gives examples of how the words are "migrated" "to specialized usage" and suggests that this "conveys some of the playful attitude that mathematicians and physicists have toward abstract, complex problems."[42]

A number of professionals in scientific and mathematical fields who wrote about their own play experiences also offer interesting insights into the reason they value play. For example, chemist Elizabeth Kean says that professional chemists "continue to have fun with chemistry throughout their careers. As one chemist recently said, 'I still like to blow things up!' Others talk about the toys they get to play with and the interesting reactions that often have powerful visual effects." Kean continues that these chemists are often the ones who "seek out opportunities to share their excitement about chemistry with young children."[43] Mathematician Sharon Whitton says, "Play has a role both in the work of mathematics and in the evolution of mathematics. Although play is not often acknowledged as a major contributing factor in mathematicians' work, their methods of inquiry resemble many of the behaviors of children involved in meaningful play." She further notes, "Math is my favorite sport. It's the game I play best."[44] Whitton believes that educators should help children see the connections between meaningful play and the work of mathematicians, creating curricula that infuse play into the teaching of mathematics.

Roger Ganschow and Lenore Ganschow note that important discoveries in the field of biological sciences were influenced by playful thinking. For example, the discovery of the DNA molecule by James Watson and Francis Crick came about through playing with various models that could be envisioned from the data many others had accumulated. Ganschow and Ganschow explain that the scientific method has "playful and nonplayful aspects, with the beginning and ending steps in the sequence being the ones that provide multiple opportunities for playfulness and are enhanced by such playfulness."[45] They state, "Science is about asking questions, and playfulness facilitates the process at the proper place and time. Best of all, engaging in scientific discovery is something that scientists enjoy doing. What could be more playful than having fun?"[46]

Although they may not use the term "playfulness," those who teach future engineers also have become increasingly aware that features of playful thought are components of their profession. Two characteristics related to playfulness are often described as important aspects of engineering work productivity: creativity and innovation. In a discussion of the importance of innovation in engineering, Andrew Milne and Larry Leifer define these terms this way: "Creativity involves the act of generating a new idea or solution concept, while innovation refers to the act of either applying some creative idea, or creatively applying a familiar idea, in such a way as to create value."[47] They observe that engineers working in teams generate ideas by thinking outside the box, commenting, "The process of innovation involves creating connections between ideas and solution concepts that are often applied outside of their normal contexts."[48] Robert Friedel and Jeanne Liedtka agree that the ability to see new possibilities is a fundamental skill of engineers, and they suggest eight ways to encourage "possibility thinking" in business as well as in engineering professions: challenging, connecting, visualizing, collaborating, harmonizing, improvising, reorienting, and playing.[49] Recently some engineering programs have focused on playful methods for educating students.[50]

Mitchel Resnick also stresses the need for an integration of play and learning. He advocates active, self-motivated playful learning in computer-related fields and indicates that this mode of learning promotes creativity.[51] He points to research suggesting that, although Singapore students score high on math and science examinations, these students lack creative thinking, and this is a concern to the Singapore government. As this example suggests, however, the educational and social-political climate in many countries does not usually support playful learning, even though professionals in computer science, physics, mathematics, engineering, and other scientific fields stress its value. Presently in most U.S. schools, the curriculum does not intentionally focus on playful learning, and sometimes play does not even occur on the school playground! Resnick says, "Unfortunately, many schools throughout the world have a similar resistance to playful learning. Teachers and administrators are often skeptical of playful learning activities, seeing them as 'just play.' Too few educators recognize the importance of leveraging student interests and passions. . . . Even in the younger grades, current trends are moving against playful learning."[52] Thus, there is a jarring contrast between the value professionals in scientific and technical fields and in higher-education science-related professional programs place on playful learning and the diminishment of it in elementary and high schools. If the professions that value creativity and innovation emphasize the need for workers who can use playful ways to be creative, act as innovative change agents, and promote change possibilities, why have school officials minimized the opportunities for playful learning?

It is time to remind educators of the value of playful learning in schools and to explain why children who are skilled at playful learning will be more likely to demonstrate creativity and innovation in their adult computer-technology, scientific, mathematical, and engineering professions.

Suggestions for Playful Learning in Schools

Some authors have observed that gifted children too often have underdeveloped skills in mathematics and science and that had these children better developed these skills, they might have chosen careers in technology, engineering, and related fields. The observations that apply to gifted children apply to other students as well.

Susan Assouline and Ann Lupkowski-Shoplik report that young children often demonstrate interest in mathematical concepts in their play and this interest is usually fostered by preschool teachers. When these children enter kindergarten, however, their interests may not be encouraged by a standardized curriculum. The result is unfortunate: "If the kindergarten curriculum requires that students learn to count from 1 to 100, then that is what they will do, even if they are already doing addition, subtraction, and multiplication. It is almost as if a child enters an elementary school, and *bam!* the door to curiosity, exploration, and individualization slams shut."[53] These authors also review an early study of Benjamin S. Bloom that asked mathematicians to think back on their early school experiences.[54] He reported that many successful mathematicians were not enthusiastic about their elementary-school experiences, and, thus, Assouline and Lupkowski-Shoplik conclude that "the special abilities of these mathematicians remained undiscovered and, therefore, underdeveloped during their elementary years."[55] They also discuss a study by Mihaly Csikszentmihalyi, Kevin Rathunde, and Samuel Whalen that examined what happened to teenagers with special interest in and talent for mathematics to find out why some cultivated their talent and others did not. These researchers found that teachers who enabled young people to follow their interests and who transmitted a joyful attitude toward learning were important influences on the students' long-term motivation to identify and pursue difficult problem solving—and later careers in mathematics.[56]

In another discussion of gifted learners, Beverly T. Sher suggests that the science curricula must "incorporate opportunities to explore findings of science research and to conduct experiments, supporting a view of inextricable integration of science content and science process" and, she stresses, a connection to "real world" problems.[57] She asserts, "The nature of science itself involves inquiry and exploration. Thus, science education should encourage habits of curiosity, observation, and logic, along with the communication skills to share ideas."[58] Those who research playful learning would agree that school environments fostering such qualities usually produce students who are more self-regulated and highly motivated to pursue problem solving and who view learning as something joyful. This can then result in students developing scientific habits of mind.

Recent academic conferences and gatherings have featured presentations that advocate the teaching of computer programming and technology design through playful, gamelike activities. Rod Parker-Rees suggests that the ability to develop technological designs depends on learning to use tools of thought in playful, innovative ways. He has outlined three learning components that assist designers of technology: a mastery orientation (increased autonomy), decentration (flexible thought), and mediation (representation of forms).[59] Ken Kahn, inventor of a computer game that teaches children how to design programs using tutorials in the form of interactive puzzles, stresses that "both children and adults enjoy the puzzles and have learned some programming skills."[60]

Thus, many professionals in computer science are engaged in finding creative and playful ways to help children learn a variety of concepts. This profession in particular appears to value the playful learning Mitchel Resnick advocates. The use of technology to enhance students' creative and innovative thinking through playful means seems to be promising, but most schools fail to realize that promise because of the drill-and-practice techniques they employ in the classrooms. Because individuals who go into computer-science fields are often open to finding playful ways to solve problems, students who experience playful-learning methods will be well prepared for work in such fields.

Successful adults reporting on their extended pretense, construction, and game play as children give evidence to the long-lasting, enjoyable, and creative benefits of play. Thus, enhancing playful learning at every level of education, including high school and college programs that prepare professionals for scientific, mathematical, and engineering fields, is warranted.

Conclusion

In an era of standardized curriculum and high-stakes testing, educators often find it difficult to take the long view about the qualities of mind they need to develop in potential computer scientists, mathematicians, chemists, physicists, and engineers. In truth, job requirements of many creative and innovative professionals make it especially important for educators to promote such abilities and to realize how the medium of play enhances their development. That makes the disregard of the value of play for mathematical and scientific learning prevalent in most of today's schools especially problematic. If we recognize the importance of play as a learning medium at all ages and if we understand that playfulness is a quality valued by adult professionals in these fields, then we may learn the greater value of playful learning in schools. Thus, playful learning could become the wave of the future!

Notes

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