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ABSTRACT

Visualization is the process by which one is able to create and sustain mental images for observation, analysis, and experimentation. This study consists of a compilation of evidence from historical examples that were collected in order to document the importance and the uses of visualization within the realm of scientific investigation. Descriptions of Archimedes, Edison, Newton, Tesla, Kekule, Einstein, Faraday, Hawking, and Galileo's use of visualization are described. (Contains 41 references.) (PR)

Scientific Visualization: A Synthesis of Historical Data

by Mark Polland

Visualization is the process by which we are able to create and sustain mental images for observation, analysis, and experimentation (Kosslyn, 1980; Samuels, 1975; McKim, 1972). It is as powerful a cognitive tool for writing (Paivio, 1971; Richardson, 1969), or math (Hadamard, 1945), as it is for carpentry, or the healing arts (Moyer, 1992; Simonton, 1979; Gawain, 1978; Goldsmith, 1957). Sports psychologists often train their athletes in visualization techniques (Gallwey, 1974). The recent Winter Olympics in Norway presented numerous opportunities to observe athletes literally visualizing their event in the moments immediately preceding their performance.

Nevertheless, aside from its function in the visual arts (Lowenfeld & Brittain, 1987; Edwards, 1986, 1979; Eisner, 1972; Arnheim, 1969), the significance of visualization is infrequently (if ever) recognized within the context of educational curricula (Ferguson, 1977).

This study consists of a compilation of evidence from significant historical examples that were collected in order to document the importance and the uses of visualization within the realm of scientific investigation (Brodlie, 1992). The reasons for the use of examples that derive from scientific sources were: 1) Visualization is more usually considered with respect to the arts than to the sciences--unfortunate, but true; and 2) that a number of documented incidents involving the use visualization in famous scientific discoveries were accessible through extensive research of the literature. The intent is, from the specific evidence presented, to make a broad argument for the (potential) importance of visualization in all areas, and especially for disciplines where visualization is not often considered. According to one writer, "The intuition of scientists can often be as visual as that of poets and painters" (Goldberg, 1983, p. 76).

The earliest documentation revealed by this study of the use of visualization in a scientific discovery dates back to Ancient Greece, although there must certainly have been earlier examples. According to one version of the famous Archimedes' legend:

> King Hieron, out of gratitude for the success of one of his enterprises, wants to consecrate a gold wreath to the immortal gods. When it is completed, the wreath is found to have the weight of the gold furnished for it; however, the suspicion arises that a portion of the gold has been replaced by a quantity of silver of the same weight. The king, being unable to force the maker of the wreath to confess, asks Archimedes for a convincing means by which to investigate the charge. One day, when the scholar, still pondering on the problem, steps into a bath, he suddenly becomes aware of the fact that the deeper he descends into the tub, the more water flows over the edge; this suggests to him all at once how he will be able to

answer the question, and he is so overjoyed at the discovery that he jumps and runs home naked, shouting "Eureka! Eureka!" (I have found it!) (Dijkstehuis, 1938, p. 18-19).

Archimedes literally *saw* the water rise and, understanding the direct connection between the volume of his own body and the measure of water displaced, immediately recognized not only the solution to the king's problem, but also a previously undescribed physical property, a physical law of nature. He was able to distill the information he acquired through direct visual observation of a real life event and to abstract its essential meaning for application to hypothetical situations.

Although the knowledge Archimedes acquired is indisputable, we cannot be sure as to whether or not Archimedes actually experienced his discovery as a visual event in his own mind. Nevertheless, it is useful as a starting point because it is ancient and legendary (especially in California where "Eureka!" is our state motto), and because it affirms the significance of visual signs in general, whether they are real life experiences or strictly mental phenomena, which is a founding premise upon which this argument is constructed.

In a process very similar to that of Archimedes, Thomas Edison was guided by visual observations of real life experiences.

> Edison created the phonograph in a single day in 1877. Years before a then-forgotten phenomenon occurred while he

> was experimenting upon the idea of sending telegraph signals from a whirling disk upon which a stylus pricked electromagnetic embossed telegraphic dots and dashes, creating a musical hum when the disk whirled at high speed. In 1877 he developed a funnel-like toy. When he talked through the funnel, the vibrations caused by his voice worked a pawl which turned a ratchet wheel connected by a pulley with a paper figure of a man operating a paper saw on a paper log. Edison noted that at times the man moved rhythmically, at times jerkily, depending upon the words shouted at the horn and the pitch of voice. Out of the setting of the musical hum, noted years previously, and the industrious paper man sawing on his paper log came the flash of insight which produced a phonograph in thirty hours (Porterfield, 1941, p. 95).

Significantly, Edison's idea for the invention of the phonograph occurred to him in the same all at once way that Archimedes' did. According to many of the examples collected here, this immediate, "Eureka!" quality seems to be a typical characteristic of discoveries or inventions that use visualization or originate in a visual experience.

In this example, Edison was able to combine information from two distinct visual observations, separated by years, which necessarily required a true act of visualization: a strictly mental phenomenon in which visual data, memories, or constructs may be observed, analyzed, and even tested. The major difference is that Edison relied on visual information from two separate events, whereas Archimedes drew on a single spontaneous observation. Because one of Edison's models was only a memory of a past event, he needed to recall, or visualize that remembered image in his mind in order to compare it with his more recent observation. Both Archimedes' discovery and Edison's invention were based on direct observations of real life events. As the following examples clearly demonstrate, the observation of real life events is not a limiting constraint in this type of problem solving.

Jacob Bronowski argues that Galileo must have been a practitioner of visualization, or visual problem solving as well:

> (T)he eye that Galileo used was the mind's eye. He did not drop balls from the Leaning Tower of Pisa--and if he had, he would have got a very doubtful answer. Instead, Galileo made an imaginary experiment (or, as the Germans say, "thought experiment") in his head, which I will describe as he did years later in the book he wrote after the Holy Office silenced him, the *Discorsi...intorno a due nuove scienze*, which was smuggled out to be printed in The Netherlands in 1638.
>
> Suppose, said Galileo, that you drop two unequal balls from the tower at the same time. And suppose that Aristotle is right--suppose that the heavy ball falls faster, so that it steadily gains on the light ball and hits the ground first. Very well. Now imagine the same experiment done again, with only one difference: this time the two unequal balls are joined by a string between them. The heavy ball will again move ahead, but now the light ball holds it back and acts as a drag or brake. So the light ball will be speeded up and the heavy ball will be slowed down; they must reach the ground together because they are tied together, but they cannot reach the ground as quickly as the heavy ball alone. Yet the string between them has turned the two balls into a single mass which is heavier that either ball--and surely(according to Aristotle) this mass should therefore move faster than either ball? Galileo's imaginary experiment has uncovered a contradiction; he say

> trenchantly, "You see from your assumption that a heavier body falls more rapidly than a lighter one, I infer that a (still) heavier body falls more slowly." There is only one way out of the contradiction: the heavy ball and the light ball must fall at the same rate, so that they go on falling at the same rate when they are tied together (Bronowski, 1977, p. 26-27).

Galileo disproved Aristotle's hypothesis by conducting an experiment exclusively through the use of arguments derived from mental visualization processes. He did not need, as Bronowski comments, to rely on external verification.

Isaac Newton's great discovery was the result of a process which was very similar Galileo's. Bronowski writes,

> (Galileo's discovery) was a few years before Isaac Newton was born, and it was all in his head that day in 1666 when he sat in his mother's garden, a young man of twenty-three, and thought about the reach of gravity. This was how he came to conceive his brilliant image, that the moon is like a ball which has been thrown so hard that it falls exactly as fast as the horizon, all the way round the earth. The image will do for any satellite, and Newton modestly calculated how long therefore an astronaut would take to fall round the earth once. He made it ninety minutes, and we have all seen now that he was right; but Newton had no way to check that. Instead he went on to calculate how long in that case the distant moon would take to round the earth, if indeed it behaved like a thrown ball that falls in the earth's gravity, and if gravity obeyed the law of inverse squares. He found that the answer would be twenty-eight days (Bronowski, 1977, p. 30).

Although, clearly, Newton's theory was accurate, in this case he was able to check his calculations through observation of the Moon's period, and found that he was right. Newton's discovery was strictly a mental process, a process of visualization, but it was confirmed by external verification. So it is clear that by the seventeenth century scientists were making major discoveries based entirely on mental visualizations.

During the last century, Nikola Tesla was designing completed inventions in his mind, reportedly, according to this first hand account, without the need for external verification or actual laboratory testing.

> I do not rush into actual work. When I get an idea I start at once building it up in my imagination. I change the construction, make improvements and operate the device in my mind. It is absolutely immaterial to me whether I run my turbine in thought or test it in my shop. *I even note if it is out of balance.* There is no difference whatever, the results are the same. In this way I am able to rapidly develop and perfect a conception without touching anything. When I have gone so far as to embody in the invention every possible improvement I can think of and see no fault anywhere, I put into concrete form this final product of my brain. Invariably my device works as I conceived that it should, and the experiment comes out exactly as I planned it. In twenty years there has not been one single exception (Tesla, 1982, p. 33).

Visualization played a key role in Kekule's discovery of the structure of the benzene molecule. According to Porterfield:

> The same process manifested itself in the creative work of Kekule, both in the development of the structural theory of the atom and in the discovery of the benzene ring theory. In the case of the first, Kekule had been visiting in the London home of a friend and was riding home on the outside of the last omnibus through deserted streets. Falling into a revery [sic], he saw atoms flitting before his eyes, two coupled together, with larger atoms seizing the smaller ones, then still larger atoms seizing three and even four smaller atoms, all whirling around in a bewildering dance, the larger atoms forming a row and dragging still smaller atoms at the end of the chain. Arriving at home, he spent the night writing down sketches of these revery [sic] pictures of the "structural theory" (Porterfield, 1941, p. 96-97).

Later on, as Kekule was drifting towards sleep, he visualized the solution to this problem of the molecular structure of benzene on which he had been working so diligently. Regarding his own process of visualization during this event, Kekule wrote,

> I turned the chair to the fireplace and sank into a half sleep. Again the atoms flitting again before my eyes. This time the smaller groups kept modestly in the background. My mental eye, rendered more acute by repeated visions of this kind, could now distinguish larger structures, of manifold conformation; long rows, sometimes more closely fitted together; all in movement wriggling and turning like snakes. And see, what was that? One of the snakes seized hold of its own tail and the image whirled scornfully before my eyes. As though in a flash of lightning I awoke; I occupied the rest of the night in working out the consequences of the hypothesis (Condensed from citations in Beveridge, 1961, p. 76; and in Goldberg, 1983, p.75-77).

The evolution of visualization in the sciences reached a significant peak in this century when Albert Einstein, then a young patent officer, had what he later called "the happiest thought of my life" (Quoted in Synge, 1960, p. 179).

> I was sitting in a chair in the patent office in Bern when all of a sudden a thought occurred to me: "If a person falls freely he will not feel his own weight." I was startled. This simple thought made a deep impression on me. It impelled me toward a theory of gravitation (Quoted in Synge, 1960, p. 179).

This thought that Einstein had while still in his teens led him eventually to the *general* theory of relativity. Einstein hypothesized, through visual thought experiments, that if a man in a falling elevator were to take his keys out of his pocket and drop them, they would stay in the same position relative to the man.

In another famous thought experiment, paraphrased by Bronowski, Einstein asked himself,

> What would the world look like if I rode on a beam of light? Suppose this tram were moving away from that clock on the very beam with which we see what the clock says. Then, of course, the clock would be frozen. I, the tram, this box riding on the beam of light would be fixed in time. Time would have stopped.
>
> Suppose the clock behind me says "noon" when I leave. I now travel 186,000 miles away from it at the speed of light; that ought to take me one second. But the time on the clock, as I see it, still says "noon," because it takes the beam of light

> from the clock exactly as long as it has taken me. So far as the clock as I see it, so far as the universe inside the tram is concerned, in keeping up with the speed of light I have cut myself off from the passage of time (Bronowski, 1973, p. 247-48).

This thought experiment led Einstein to the *special* theory of relativity. Although many of Einstein's discoveries were only confirmed after his death, and some of them we are still unable to verify in the real world, his theories have significantly altered both scientific and popular conceptions with regard to the physical nature of the universe.

In response to a psychological survey of mathematicians conducted by Jacques Hadamard (Hadamard, 1945), Einstein wrote,

> The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined.
>
> There is, of course, a certain connection between those elements and relevant logical concepts. It is also clear that the desire to arrive finally at logically connected concepts is the emotional basis of this rather vague play with the above mentioned elements. But taken from a psychological viewpoint, this combinatory play seems to be the essential feature in productive thought--before there is any connection with logical construction in words or other kinds of signs which can be communicated to others.
>
> The above mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs

> have to be sought for laboriously only in a second stage, when the mentioned associative play is sufficiently established and can be reproduced at will (Hadamard, 1945, p. 142-43).

Although this study is focused primarily on what Einstein refers to as visual types of signs and images, it is also interesting to note Einstein's use of the word muscular in this context. We may never know exactly what Einstein meant by that statement, but it is the contention of this author that he intended to convey the sense of a physical component sometimes with (his) mental images. This is demonstrated by imaging (visualizing) the sensation of falling, an example appropriate to Einstein's own investigations, which can produce, or re-create that feeling in the pit of your stomach that accompanies falls (or earthquakes) of a certain magnitude.

With regard to these same issues, Einstein later wrote,

> We have forgotten what features in the world of experience caused us to frame (pre-scientific) concepts, and we have great difficulty in representing the world of experience to ourselves without the spectacles of old-established conceptual interpretation. There is the further difficulty that our language is compelled to work with words which are inseparably connected with those primitive concepts. These are the obstacles which confront us when we try to describe the essential nature of the pre-scientific concept of time (Quoted in Bronowski, 1973, p. 255-56).

According to one writer, the famous Nobel Laureate scientist Richard Feynman certainly would have agreed with Einstein.

> The reason Dick's physics was so hard for ordinary people to grasp was that he did not use equations. The usual way theoretical physics was done since the time of Newton was to begin by writing down some equations and then to work hard calculating solutions of the equations. This was the way Hans and Oppy and Julian Schwinger did physics. Dick just wrote down the solutions out of his head without ever writing down the equations. He had a physical picture of the way things happen, and the picture gave him the solutions directly with a minimum of calculation. It was no wonder that people who had spent their lives solving equations were baffled by him. Their minds were analytical; his was pictorial (Dyson, 1979, p. 55-56).

Michael Faraday was famous as a visual thinker also. Goldberg writes that:

> The intuition of scientists can often be as visual as that of poets and painters. One of the most interesting visual intuiters [sic]--and one of the more important--was the nineteenth-century British physicist Michael Faraday. Among other things, Faraday developed the first dynamo and electric motor, ideas that originated in his mental vision of the universe as a composite of curved tubes through which energy radiated. Faraday also laid the foundation of modern field theory with ideas that developed out of his images of "lines of forces" surrounding magnets and electric currents (Goldberg, 1983, p. 76-77).

Goldberg continues with an example from another famous scientist, Mendeleev, "...awakening with the image, virtually in its entirety, of the Periodic Table of the Elements" (Goldberg, 1983, p. 77).

The most recent example uncovered by this study is of Stephen Hawking, who, because he is unable to speak or write due to his affliction with Arterial Lateral Sclerosis (ALS, or Lou Gehrig's disease), is forced to communicate through the use of a computer designed specifically for him. In the movie about Hawking titled "A Brief History of Time" (based on Hawking's book of the same title), he says, through the computer generated voice, that because of his impediment: "I tended to think in pictures and diagrams I could visualize in my head" (see Hawking, 1992). Regardless of his physical limitations, Hawking is able to probe the origin of the universe, the nature of time, and the physical properties of black holes, all from the confines of his wheelchair through his use of visualization.

Through the use of visualization, scientists are able to examine not only things they have never seen, but also to observe things that never could be seen. What more powerful too could they have? What remains to be seen are the ways in which these important techniques of visualization will be implemented and facilitated by educational curricula in the future.

References

Arnheim, R. (1969). *Visual thinking.* Berkeley, CA: University of California Press.

Beveridge, W. I. B. (1961). *The art of scientific investigation.* NY: Vintage.

Brodlie, K. W. (Ed.) (1992). *Scientific visualization.* NY: Springer-Verlag.

Bronowski, J. (1956). *Science and human values.* NY: Harper & Row.

Bronowski, J. (1965). *The identity of man.* Garden City, NY: Natural History Press.

Bronowski, J. (1973). *The ascent of man.* Boston: Little, Brown.

Bronowski, J. (1977). *A sense of the future.* Cambridge, MA: MIT Press.

Bronowski, J. (1978a). *The origins of knowledge and imagination.* New Haven, CT: Yale University Press.

Bronowski, J. (1978b). *The visionary eye.* Cambridge, MA: MIT Press.

Dijkstehuis, E. J. (1938). *Archimedes.* NJ: Princeton University Press.

Dyson, F. (1979). *Disturbing the universe.* NY: Harper & Row.

Edwards, B. (1986). *Drawing on the artist within.* NY: Simon & Schuster.

Edwards, B. (1979). *Drawing on the right side of the brain.* Los Angeles: Tarcher.

Einstein, A. (1921). *The meaning of relativity.* NJ: Princeton University Press.

Einstein, A. (1954). *Ideas and opinions.* NY: Crown.

Eisner, E. W. (1972). *Educating artistic vision.* NY: Macmillan.

Ferguson, E. S. (1977). *The mind's eye: Nonverbal thought in technology. Science, 197,* 4306.

Frank, P. (1947). *Einstein: His life and times.* NY: Alfred Knopf.

Gallwey, W. T. (1974). *The inner game of tennis.* NY: Bantam

Gawain, S. (1978). *Creative visualization.* San Rafael, CA: New World Library.

Ghiselin, B. (1952). *The creative process.* Berkeley, CA: University of California Press.

Gleick, J. (1992). *Genius.* NY: Pantheon.

Goldberg, P. (1983). *The intuitive edge.* Los Angeles: Tarcher.

Goldsmith, J. (1957). *The art of spiritual healing.* NY: Harper & Row.

Hadamard, J. S. (1945). *The psychology of invention in the mathematical field.* NJ: Princeton University Press.

Harman, W. & Rheingold, H. (1986). *Higher creativity.* Los Angeles: Tarcher.

Hawking, S. W. (1988). *A brief history of time.* NY: Bantam.

Hawking, S. W. (1992). *A brief history of time: A reader's companion.* NY: Bantam.

Kosslyn, S. M. (1980). *Image and mind.* Cambridge: Harvard University Press.

Lowenfeld, V. & Brittain, W. L. (1987). *Creative and mental growth.* NY: Macmillan.

McKim, R. H. (1972). *Experiences in visual thinking.* Monterey, CA: Brooks/Cole.

Moyer, B. (1992). *Healing and the mind.* (Television Special Report.) Washington, DC: Public Broadcasting Service.

Paivio, A. (1971). *Imagery and verbal processes.* NY: Holt, Rinehart & Winston.

Porterfield, A. (1941). *Creative factors in scientific research.* North Carolina: Duke University Press.

Richardson, (1969). *Mental imagery.* NY: Springer.

Rossman, J. (1931). *The psychology of the inventor.* Washington, DC: Inventors.

Samuels, M. (1975). *Seeing with the mind's eye.* NY: Random House.

Simonton, O. C. (1979). *Getting well again.* Los Angeles: Tarcher.

Synge, J. L. (1960). *Relativity, the general theory.* NY: Interscience.

Tesla, N. (1982). *My inventions.* Williston, VT: Hart Brothers.

West, T. G. (1991). *In the mind's eye.* Buffalo, NY: Prometheus.