DOCUMENT RESUME

ED 393 593 PS 024 111

AUTHOR	Polland, Mark J.
TITLE	Mental Imagery in Creative Problem Solving.
PUB DATE	96
NOTE	205p.; Ph.D. Dissertation, Claremont Graduate School.
PUB TYPE	Dissertations/Theses - Doctoral Dissertations (041)
EDRS PRICE	MF01/PC09 Plus Postage.
DESCRIPTORS	Artists; Authors; Creativity; *Discovery Processes; Imagination; Inventions; Musicians; *Problem Solving; *Productive Thinking; *Scientists; Spontaneous Behavior; Visual Arts; *Visualization
IDENTIFIERS	*Creative Problem Solving; *Mental Imagery

ABSTRACT

In order to investigate the relationship between mental imagery and creative problem solving, a study of 44 separate accounts reporting mental imagery experiences associated with creative discoveries were examined. The data included 29 different scientists, among them Albert Einstein and Stephen Hawking, and 9 artists, musicians, and writers, including Leonardo da Vinci and Richard Wagner. Thirty-three of the incidents were reported by the subjects themselves, and 11 were written by biographers and historians. The study analyzed reports of mental imagery according to the following three factors: (1) possible causes for the reported perception of mental imagery; (2) what perceptual modalities were involved in the reported mental imagery; and (3) at what stage in the problem solving process imagery was reportedly involved. Findings included the following: (1) mental images occurred more often in a spontaneous way when the subjects were occupied with routine behaviors; (2) imagery that occurred in the visual modality was the single most reported factor, which may reflect the fact that the research focused on scientific fields that tend to rely on visual representations; and (3) mental imagery was reported to occur most frequently during the later stages in the creative process. Contains approximately 305 references. (AJH)

Mental Imagery in Creative Problem Solving.

by Mark J. Polland

A Dissertation submitted to the Faculty of Claremont Graduate School in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Graduate Faculty of Education.

Claremont, CA

1996

Approved by:

John O. Regan

We, the undersigned, certify that we have read this dissertation and approve it as adequate in scope and quality for the degree of Doctor of Philosophy

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Dedication

To my mother, Barbara Kay Polland, for her endless commitment and support.

To John Regan, whose vision is a guiding light.

And to my Grandmother and Grandfather, who helped to make this dream a reality.

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Chapter 1

1.1 Abstract

A number of scientists, as well as artists, musicians and writers have reported experiencing mental imagery in conjunction with significant creative discoveries. Is it possible to learn about the creative from these reported experiences? This study presents a total of 44 separate accounts reporting mental imagery experiences associated with creative discoveries. The data include 29 different scientists and 9 artists, musicians and writers. Thirty-three (33) of the incidents were reported by the subjects themselves, and 11 were written by biographers and historians. The reports were collected from research into the literature concerning "mental imagery," "the creative process," and "scientific discovery."

Do these reported experiences have any characteristics in common? Do they suggest a connection between mental imagery and creative problem solving? This study analyzed reports of mental imagery according to these three factors:

1. Possible causes for the reported perception of mental imagery, including behavioral, psychological and environmental factors. What was the person doing and thinking at the time? Could that behavior have facilitated the reported imagery? Were other incidents of mental imagery reported, either in association with the experience in question or not?

2. What perceptual modalities were involved in the reported mental imagery? Though mental imagery is often associated with the visual modality, it is not limited to perceptions in the visual mode (see what are mental images below). Were non-visual modalities involved? Are multiple modalities indicated? Is there a

connection between the specific type of problem and the mode of perception?

3. At what stage in the problem solving process was imagery reportedly involved? What function did the reported mental imagery perform in facilitating the problem solving process? To what degree, if any did the reported imagery contribute to the completed solution?

The purpose of the analysis is to develop a profile that outlines both the range and frequency of the data within each of three factors, insofar as it may be determined from the accounts presented. It is possible to determine any common factors in these reports that might provide insight into the creative process? Are there ways to develop this kind of (reported) creative behavior, or to teach it to others?

Such reports are unverifiable because they represent purely cognitive phenomena. However, the significance of the discoveries associated with the accounts of imagery presented here warrants consideration of the reported circumstances involved.

1.2 Introduction

Mental imagery is more commonly associated with the arts, such as painting and poetry, than with the scientific problem solving. This study documents reported incidents of mental imagery in a wider context, specifically broadening the scope to encompass the field of scientific discovery. Mental imagery has been reported in conjunction with a number of significant discoveries. Einstein, for example, reported that the Theory of Relativity was first conceived as a mental image. This study examines the role of mental imagery in scientific discoveries in an effort to develop a broader, as well as a deeper understanding of the creative process.

The data present a compilation of anecdotal accounts reporting the perception of mental imagery in association with scientific discoveries. The data provide two functions. They document the importance of mental imagery in scientific discovery; and second, they provide the material with which to analyze the unique characteristics of this reported phenomenon. What are these characteristics like, and is it possible to determine any factors that may facilitate these experiences? Is it possible to develop or teach these abilities?

Although accounts from nine artists, musicians and writers are included, the primary focus of the data is on the thirty scientists and inventors presented. The emphasis on the sciences is for two reasons. First, as mentioned above, mental imagery is less commonly associated with scientific investigation, and this may not reflect an accurate assessment of this relationship. Second, the products of creative problem solving in the sciences are (generally) less subjective than in the arts. This is to preclude any question that the data represent creative accomplishments. The group of artists, composers, etc., are included as a foil to the larger body of data from the sciences, and to further identify the range of reported imagery experiences within the larger scope of creative behaviors.

1.3 Summary

Fifteen reported incidents were found to meet the standards of the primary data, and forty-four for the combined primary and secondary. The single most frequently reported factor was imagery that occurred in the visual modality, though imagery in the auditory and tactile/kinesthetic modalities were also reported. The frequency of reported imagery experiences in the visual mode may reflect the types of investigations represented. Physics and mechanical engineering both tend to rely on pictures (diagrams), suggesting that relevant imagery was more likely to have been perceived in the visual mode. All four composers included in the secondary data reported to have perceived auditory (musical) imagery.

There were twenty-two different factors found that may have contributed to the imagery experiences reported in the primary data, and twenty-four in the combined results. The individual factors measured relatively low frequencies, however, several factors seem to indicate a similar trend toward a range of activities involving common everyday behaviors. Results of this study indicate that mental images occurred more often in a spontaneous, unexpected way while the subjects were relaxing or otherwise preoccupied with routine behaviors. Specific behaviors include walking, sitting, riding in a bus or carriage, lying down, and sleeping. These behaviors may have provided a certain degree of distraction perhaps, but were not so demanding that they required complete and undivided attention. Not thinking about the problem when the solution occurred, and not consciously directing the imagery were two of the most frequent factors; they may also be related to the same trend.

The results suggest that mental imagery more often occurs in conjunction with routine behaviors while the subject may not be aware that they were thinking about a specific problem at the time. This study suggests that mental imagery is often the result of indirect causes, though a few people reported to have perceived them at will. The data suggest that mental imagery has occurred across the range of stages in the creative process (see below), but mental imagery was reported to occur more frequently during the later stages (illumination, verification). Several imagery experiences were reportedly accompanied by affective qualities; in some instances the affective qualities were perceived as positive, in others they were perceived as negative.

Mental imagery has been reported in conjunction with a range of creative behaviors from fiction to physics. Although mental imagery is more often associated with fiction, this study helps to establish the significance of mental imagery within the scope of scientific reasoning. One of the remarkable aspects of mental imagery is its application to scientific observation and experimentation. In several cases scientifically verifiable results have been reported from experiments conducted exclusively within an individual's mind.

Dream-like imagery, such as sleeping dreams and hypnagogic experiences was reported with surprisingly high frequency in conjunction with scientific discoveries, confirming the theories of several writers that conscious thought processes are sometimes an impediment to creativity. Apparently this is true not only in the arts but in the sciences as well.

Though there were cases where mental imagery skills were reportedly developed through practice and exercise, these reports were rare, reportedly occurring in only two cases in the primary data, and a total of three in the combined. In cases where mental imagery was not a customary part of the thinking process, it was reported to occur more often by not thinking about the problem than by thinking about it. As Kekule wrote, "Let us learn to dream . . ."

1.4 What are mental images?

Mental images are distinguished from other cognitive processes by the experience of sensory perceptions; however these perceptions are different from normal sensory perceptions (of the external world) because they are disassociated from stimuli in the immediate physical environment. Within the context of this study, the word "image" is used to refer not only to visual perceptions but to perceptions across the spectrum of sensory modalities: an image is a representation of a sensory perception. Accordingly, a "mental image" is the internal recreation or representation of a sensory perception and may involve multiple sensory modalities. Although they are less frequently cited, there is cause to suspect that non-visual modalities play a significant role in creative problem solving. Miller writes that "Mental imagery in auditory, sensual, *and* visual modes has played a central role in creative thought" (1984, p. 221). The research for this study has revealed several cases involving non-visual modalities. Unfortunately, the evidence from non-visual modalities has not been sufficiently developed in the literature as of yet. This may change with future research.

Mental images are potentially comprised of visual, auditory, gustatory, olfactory and/or tactile/kinesthetic sensations. Mental images that are perceived in the visual modality are described as pictorial if they represent the perception of scenery or solid forms, like but not limited to photographic representations. Visual mental images are described as diagrammatic if they involve schematic types of representation, like blueprints or transparent line drawings. The categories overlap; but sometimes they provide a useful distinction. I reserve the word graphic to denote real, not mental images. Actual photographs, as well as paintings, blueprints and written text are graphic.

Auditory images represent acoustic perceptions. Reports of hearing "voices" suggest the perception of auditory imagery, but these images may also carry a verbal content, as do visual images involving the perception of words printed on a page. It is the perception of a sensory component that distinguishes mental imagery from other cognitive processes. This definition of mental imagery is in accordance with several leading contemporary researchers in this field. Paivio described the difference between images and verbal representations in this way:

> Images are thought to be concrete (i.e., they represent specific instances and are modality specific) and parallel, in contrast to verbal representations, which are abstract (can represent classes directly and are amodal) and sequential (from Pinker & Kosslyn, 1983, p. 48).

Although this distinction is helpful, imagery and verbal representations are not mutually exclusive and often, if not usually, occur in conjunction with one another. Nevertheless, there are apparent differences. Bower states that:

Images provide a kind of "direct contact" with the appearance of a thing by essentially recreating the experience of seeing it; verbal or propositional representations do not evoke a precept like experience but convey information only about a thing's properties. The two sorts of information are stored in qualitatively different kinds of codes (from Pinker & Kosslyn, 1983, p. 48).

Though this may simply have been an oversight, Bower weakens his argument by unnecessarily limiting his discussion to imagery in the visual mode. Still, the proposition that imagery is stored in different kinds of codes from verbal representations suggests that it may be subject to different processing mechanisms.

The application of the term mental imagery to the range of (disassociated) sensory perceptions is also consistent with Scheibel and Scheibel's use of the term: "not-object-bound sensory phenomena" (Scheibel & Scheibel, 1962). Their rationale for applying this blanket term is that, "the mechanisms underlying hallucinations are the same as, or at least are overlapping with, the mechanisms that mediate other imaginal states such as dreams, eidetic images, intense memory images, etc." (Scheibel & Scheibel, 1962, p. 17).

Horowitz wrote, "Any thought representation that has a sensory quality we call an image" (Horowitz, 1978, p. 3). The sensory quality, as Horowitz puts it, of images is based on the appearance of a physical correspondence, or resemblance; though, as previously mentioned, this correspondence is not limited to strictly visual correspondences but extends across the range of modalities.

Daniel Dennett writes that,

An image represents something else always in virtue of having at least one quality or characteristic of shape, form or color in common with what it represents. Images can be in two or three dimensions, can be manufactured or natural, permanent or fleeting, but they must *resemble* what they represent and not merely represent it by playing a role--symbolic, conventional or functional--in some system (Dennett, 1981, p. 52).

Finke, like Dennett, also writes that images *resemble* (external) sensory stimulus.

> Mental imagery is defined as the mental invention or recreation of an experience that in at least some respects resembles the experience of actually perceiving an object or event, either in conjunction with, or in the absence of, direct sensory stimulation (Finke, 1989, p. 2).

Finke distinguishes mental images from the real or actual perception of the external world, although this is somewhat confusing because he also indicates that mental imagery can occur "in conjunction with direct sensory stimulation."

The academic debate concerning mental imagery centers largely around this issue concerning the cognitive structures that enable mental images to be perceived. Visual mental images do not involve seeing through the eyes, but, somewhere down the line the information from both systems is processed in similar ways. There may be cognitive and/or neurological connections fundamental to both systems. Although the research in this area is focused almost exclusively on visual imagery, there are presumably implications for the study of other modalities as well. As the poet William Blake wrote: "Those are led to believe a lie who see with, not through the eyes."

Stephen Kosslyn is a leading contemporary researcher in this field and represents a school of thought that maintains images are like projections in an imaginary three dimensional space. Kosslyn describes imagery as an "array like medium, also subserving visual perception, that mimics a coordinate space" (Pinker & Kosslyn, 1983, p. 52). This theory is closely related to a proposal by Shepard, who wrote:

An imagined or perceived shape is represented as a set of points, with each point embedded in a multidimensional "space" with its own non-Euclidean geometry. These spaces do not literally correspond to isolatable spatial regions of the brain, but they presumably reside in neural networks whose interconnections mimic the hypothesized geometry of the space (i.e., the strength of the connections between neurons, or perhaps neural assemblies, is proportional to the distance between corresponding points in the abstract "space" posited by the theory) (from Pinker & Kosslyn, 1983, p. 59).

While Kosslyn concludes that "imagery is centrally involved in directing thought processes" (Forisha, 1983, p. 318), and furthermore that "imagery itself places constraints on thought" (Forisha, 1983, p. 318), this is in direct contrast to other researchers in this field, such as Pylyshyn, who attributes less significance to the role of mental imagery. Pylyshyn maintains that "imagery is a by-product of thought that is directed by underlying knowledge and belief systems" (Pylyshyn, 1979, 1973; Forisha, 1983, p. 318).

Although researchers still disagree as to the specific nature of mental images, the collective effort in this area has led one group of researchers to conclude that, "This work has helped to establish that mental images consist of more that just verbal description or propositions" (Finke, Ward & Smith, 1992, p. 47).

Chapter 2

2.1 Importance: Problems in the observation of creative behaviors

Thinking is one thing, the perception of our thoughts another . . . We are always thinking, but we do not always perceive our thoughts. Plotinus (from Montmasson, 1932, p. 41).

Because it is difficult, as Plotinus wrote, "to perceive our thoughts," even under normal conditions, the situation is exacerbated when it comes to unraveling the thought processes involved during extraordinary conditions, such as significant creative discoveries. For this reason, the reports of mental imagery associated with scientific discoveries provide a unique opportunity to study the creative process from an internal perspective, if only insofar as these sometimes sketchy anecdotal reports permit.

Rudolph Arnheim, author of *Visual Thinking*, wrote, "The human mind is not easily accessible. Nobody ever comes to know more than one specimen of mind directly" (Arnheim, 1974, p. 7). Arnheim succinctly addressed the very issue that inevitably poses problems in the observation of creative behaviors. As the data collected for this study confirm, creativity can be an unobservable mental phenomenon. The products of scientific inquiry in particular are often abstract theoretical constructs; rarely are they as tangible as works of art (conceptual art notwithstanding). If we had been standing right next to Einstein in that Swiss patent office when the Theory of Relativity first came to him, would we have known that something remarkable had occurred?

Nikola Tesla, the inventor of the AC generator who is discussed in detail below, believed that someday it would actually be possible to record mental images in such a way that we could all share our internal perceptions.

> If my explanation is correct, it should be possible to project on a screen the image of any object one conceives and make it visible. Such an advance would revolutionize all human relations. I am convinced that this wonder can and will be accomplished in time to come; I may add that I have devoted much thought to the solution of the problem (Tesla, 1919, p. 32).

This possibility is also realized in a provocative way in a recent science fiction film by Wim Wenders (1992, *Until the End of the World*).

Pablo Picasso wrote,

> It would be very interesting to record photographically, not the stages of a painting, but its metamorphoses. One would see perhaps by what course a mind finds its way toward the crystallization of its dream (from Ghiselin, 1952, p. 56; in Feldman, 1980, p. 112; cf. Clouzot, *The Mystery of Picasso*, film).

The film titled *The Mystery of Picasso* (Henri-Georges Clouzot, released 1982), records exactly what Picasso described. It shows the creation of a painting from beginning to end, yet it also provides a deeper sense of the image that Picasso was striving to achieve, his frustrations and erasures leading to new visions, and new images. Studies leading up to *Guernica*, his monumental painting in response to the atrocities of the Spanish Civil War provide a similar insight into the mind of the creator (see Arnheim, 1962; Russell, 1980; Chipp, 1988; Oppler, 1988; see also Arnheim 1992, p. 74 ff.; Arnheim, 1974, p. 6 ff.; Gardner, 1993, p. 172 ff.).

In his statement, Picasso was referring to painting, but scientific discovery or invention could be substituted for painting and the statement remains true. When discoveries emerge before or independent of tangible results or products, mental images sometimes provide a rare glimpse into that creative process. Picasso continued:

> What is really very curious is to see that the picture does not change basically, that the initial vision remains almost intact in spite of appearances . . . I perceive, when this work is photographed, that what I have introduced to correct my first vision has disappeared, and that after all the photographic image corresponds to my first vision, before the occurrence of the transformation brought about by my will (from Ghiselin,

1952, p. 56; in Feldman, 1980, p. 112; cf. *The Mystery of Picasso*, film).

As data collected for this study demonstrate, many scientific discoveries have occurred in a complete way, similar to Picasso's experience, by means of an initial mental image (cf. Tesla; Einstein; Snyder; Mozart; et al). The moment of creativity is difficult if not impossible to predict, even when it involves an objectively tangible event, like the creation of a painting by a master. The reports of mental imagery associated with creative achievements provide a small window into that subjective and elusive experience. This study uses those reports as a way to learn about the moment of creative discovery, and to circumvent some of the difficulties inherent in the observation of creative behaviors.

2.2 Data Validation

There is every indication that the discoveries cited in this study describe authentic creative behaviors. Many were instrumental not only in the progress of science and technology, but also in the evolution of human thought. In cases where first person accounts were unavailable, every effort was taken to ensure the information was collected from authoritative sources. Many of the cases are cited repeatedly within the literature, further validating their historical credibility. All accounts that could reasonably be interpreted as reports of mental imagery in association with creative achievements were included.

Several artists and writers are considered in the secondary data section, but the primary body of evidence focuses on creative achievements resulting in objectively verifiable conclusions. This was to ensure that the primary data represent unquestionably creative incidents. This study is concerned with the role of mental imagery in creative behavior; in and of itself, mental imagery does not necessarily constitute a creative behavior.

2.3 Describing mental images

Mental phenomena are often difficult, and sometimes impossible to describe with words, not only because they may be perceived as nonverbal signs but also because the language to describe those experiences may not yet have been invented. Scientists face the same difficulties in the attempt to codify and communicate new findings. Heisenberg wrote,

> (The) problems of language here are really serious. We wish to speak in some way about the structure of the atoms and not about the "facts"--the latter being for instance, the black spots on a photographic plate or the water droplets in a cloud chamber. *But we cannot speak about the atom in ordinary language* (Heisenberg, 1958, p. 179; see Shepard, 1978, p. 139).

And Einstein 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 (from Bronowski, 1973, p. 255-56; in Schlipp, 1952).

Mental images are similar to the structure of the atom or the concept of time because they are unobservable phenomena, at least to an objective eye. But, imagery is susceptible to verbal description because by definition mental images resemble sensory perceptions. This resemblance, or iconic nature of mental images enables them to be described and communicated with the same encyclopedic vocabulary that applies to the objects they represent. The images described in these data are often simplistic in nature and readily accessible to verbal description. Of course, as Heisenberg acknowledged, there are images that are difficult if not impossible to describe with words.

In the eighteenth century, David Hume wrote:

> There is a great resemblance betwixt our impressions and ideas in every other particular, except their degree of force and vivacity. The one seem to be in a manner the reflection of the other; so that all the perceptions of the mind are double, and appear both as impressions and ideas. When I shut my eyes and think of my chamber, the ideas I form are exact representations of the impressions I felt; nor is there any circumstance of the one, which is not to be found in the other. In running over my other perceptions, I find still the same resemblance and representation. Ideas and impressions appear always to correspond to each other (Hume, 1739).

The correspondence between the sensory perceptions involved with mental images and the perception of things or places in the real world result in the potential to describe both types of perceptions using the (encyclopedic) vocabulary of sights and sounds of everyday life. This is not to say that all mental images are verbally translatable, or that nothing is lost in the process, but in general it is possible to convey, through words, the essential nature of a particular mental image.

Insofar as mental images are subject to verbal description, they may be communicated to other people. Through language, imagery provides a connecting link that enables us to recreate, to greater or lesser degrees, iconic facsimiles of other peoples' internal perceptions. Mental imagery seems to be unique in this regard.

Einstein wrote,

> By the aid of language different individuals can, to a certain extent, compare their experiences. Then it turns out that certain sense perceptions of different individuals correspond to each other (Einstein, 1922, pp. 1-2).

We can never know if the images we might construct in response to the descriptions included in this study is identical to their author's reported perception, but the message can be transferred, or translated, so that the essential content is communicated.

2.4 Creativity in Education

This study is not intended as a prescription for the use of mental imagery in academic curricula, but it does demonstrate the importance of mental imagery as a creative behavior. Creativity is an integral aspect of scientific investigation, and education in the sciences should offer the opportunity to foster creative development. Unfortunately, this is not always the case.

Although Einstein was reportedly "never much good at the 'easy' part of mathematics" (West, 1991, p. 121), the schools he attended consistently neglected to recognize his special talent. His personal experiences led Einstein to conclude that:

> It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of freedom; without this it goes to wrack and ruin without fail (from Schlipp, 1979, p. 17).

In a profile on Einstein, West (1991) wrote that:

> (A)rithmetic proficiency with speed and accuracy of calculation and response is still widely considered to be a major early indicator of mathematical aptitude, whether in the classroom or a work group, or in achieving high scores on standardized aptitude tests. In all these settings the main concern is getting the largest number of answers right in a given time... The inadequacy of such teaching and testing methods to recognize deep mathematical ability beneath superficial difficulties cannot be overemphasized.

A report from the National Research Council (1989) stated that:

> "As computers increase in power, some parts of mathematics become less important while other parts become more important. While arithmetic proficiency may have been "good enough" for many in the middle of the century, anyone whose mathematical skills are limited to computation has little to offer today's society that is not better done by an inexpensive machine (National Research Council, 1989, p. 45).

These arguments are aimed primarily at education in the sciences, but similar arguments can be made for education in the humanities. Is early proficiency with reading and writing an accurate indicator of an individuals ability to express themselves verbally? West presents evidence to suggest that early language development is not necessarily indicative of linguistic skills at later stages of development (West, 1991, see profiles on Churchill and Yeats, et al.). These perspectives suggest that a more wholistic approach to the development of each student as an individual in a complex society may be in order.

Chapter 3

3.1 Literature Review

> *When I examine myself and my methods of thought, I come to the conclusion that the gift of fantasy has meant more to me than my talent for absorbing knowledge.* Albert Einstein (from Clark, 1971, p. 87).

The earliest known literature to address the subject of mental imagery dates back to Ancient Greece. Simonides, an Ancient Greek scholar, reportedly used visual imagery as a way to increase his memory capacity (McKellar, 1972, p. 35). Aristotle, who referred to Simonides in his writings, believed that thinking without imagery was impossible (McKellar, 1972, p. 37; Mandler & Mandler, 1964, pp. 9-15). Aristotle wrote,

> If one perceived nothing one would learn and understand nothing . . . Whenever one is contemplating, it is some image that one is contemplating; for the images are like sense-data but without matter . . . What then, distinguishes the *primary* thoughts from being images? Is it not better to say that neither they nor the others *are* images, but that they cannot occur without images? (Aristotle, 1986, p. 210).

Ludwig Boltzman was entirely in agreement with Aristotle. In 1897, Boltzman wrote, "I cannot think of any other law of thought than that our pictures should be clearly and unambiguously imaginable" (from Miller, 1984, p. 51). Boltzman continued:

> It is precisely the unclarities in the principles of mechanics that seem to me to derive from not starting at once with hypothetical mental pictures but trying to link up with experience from the outset (from Miller, 1984, p. 76).

The conviction that imagery is an essential feature of thought carried into this century as well. Based on his own subjective observations, Titchener reported that "My mind, in its ordinary operations, is a fairly complete picture gallery" (Titchener, 1909, p. 187; see Shepard, 1978, p. 156).

Citing two of the most eminent psychologists, Horowitz reported that Freud and Piaget both were convinced of the primacy of mental imagery.

> Freud postulated that the earliest thinking in infancy was in hallucinatory images for the purpose of temporary, if imaginary, gratification. In a parallel line of reasoning, Piaget suggested that whenever the preverbal child experienced desire he might form in his mind an image (Horowitz, 1978, p. 77).

Although children often seem to have especially vivid imagery abilities, imagery is a crucial aspect of adult thought processes as well. "This ability to form pictorial images is inherent in the human brain and provides people with an alternate way of thinking about things" (Starker, 1985, p. 4).

Ferguson states that "Much of the creative thought of the designers of our technological world is nonverbal; its language is an object, or a picture or a visual image in the mind" (Ferguson, 1977, p. 835). His conclusion is that "'Thinking with pictures is an essential strand in the intellectual history of technological development" (Ferguson, 1977, p. 827). David Hume also commented on this facility.

> To join incongruous shapes and appearances costs the imagination no more trouble than to conceive the most natural and familiar objects . . . this creative power of the mind amounts to no more than the faculty of compounding, transposing, augmenting, or diminishing the material afforded us by the senses and experience (Hume, 1748; from Shepard & Cooper, 1982, p. 1).

Herman von Helmholtz wrote,

> Thus the memory images of pure sense impressions can also be used as elements in combinations of ideas, where it is not necessary to describe these in words. Equipped with an awareness of the physical form of an object, we can clearly imagine all of the perspective images which we may expect upon viewing from this or that side, and we are immediately disturbed when such an image does not correspond to our expectations. Indeed, the idea of a three-dimensional figure has no content other than the ideas of the series of visual images which can be obtained from it, including those which can be produced by cross-sectional (Helmholtz, 1894; from Miller, 1984, p. 49; Warren & Warren, 1968, pp. 252-54; Shepard, 1978, p. 133; Shepard & Cooper, 1982, p. 1).

Some of the literature on the role of mental imagery in creativity tends to emphasize the importance of "visual thinking" over the auditory and other domains as a cognitive approach. Arnheim wrote:

> A review of what is known about perception, and especially about sight, made me realize that the remarkable mechanisms by which the senses understand the environment are all but identical with the operations described by the psychology of thinking. Inversely, there was much evidence that truly productive thinking in whatever area of cognition takes place in the realm of imagery (Arnheim, 1969, p. v; cf. Lowenfeld, 1939; Lowenfeld & Brittain, 1951; Gardner, 1973; 1982; Edwards, 1986).

This emphasis has historical antecedents. During the High Renaissance, the scholar Thesoledia wrote, "Conceptual thinking is built on visual understanding. Visual understanding is the basis of all knowledge" (from Mandler & Mandler, 1964). This emphasis on the visual mode seems over stated now, but "visual understanding" is certainly a fundamental way of knowing.

3.2 Thinking without words

Several important writers on the subject of mental imagery have themselves expressed an inclination toward imagery as a method of thought. Francis Galton, who wrote the first in depth study of mental imagery in 1883 (see reports of mental imagery below), reported great difficulties in communicating his own thoughts through verbal means.

> It is a serious drawback to me in writing, and still more in explaining myself, that I do not so easily think in words as otherwise. It often happens that after being hard at work, and having arrived at results that are perfectly clear and satisfactory to myself, when I try to express them in language I feel that I must begin by putting myself upon quite another intellectual plane. I have to translate my thoughts into a language that does not run evenly with them. I therefore

waste a vast deal of time in seeking for appropriate words and phrases, and am conscious, when required speak on a sudden, of being often very obscure through mere verbal maladroitness, and not through want of clearness of perception. That is one of the small annoyances of my life (in Hadamard, 1945, p. 69; cf. Tyrrell, 1946, p. 34; Edwards, 1986, p. 47; Simonton, 1988, p. 27; cf. Shepard, 1978, p. 139-40).

Jacques Hadamard was author of *The Psychology of Invention in the Mathematical Field* (1945). He is discussed in greater detail below (see Hadamard under primary data). As Hadamard himself acknowledged, he experienced difficulties similar to Galton's.

> I insist that words are totally absent from my mind when I really think and I shall completely align my case with Galton's in the sense that even after reading or hearing a question, every word disappears at the very moment I am beginning to think it over; words do not reappear in my consciousness before I have accomplished or given up the research, just as happened to Galton (Hadamard, 1945, p. 75; cf. Shepard, 1978, p. 140).

Einstein went so far as to write that, "I have no doubt but that our thinking goes on for the most part without the use of signs (words) and beyond that to a considerable degree unconsciously" (Holton, 1978a; in French, 1979, p. 156; for a continued discussion see Einstein below). Certainly Galton, Hadamard, and Einstein were unusual cases, but perhaps other people experience their own thoughts in similar, nonverbal ways.

3.3 Reports of mental imagery

3.3.1 Francis Galton

Galton, who was already presented in this study (see thinking without words above), was the first writer to attempt a comprehensive treatise on mental imagery titled *Inquiries into Human Faculty and its Development* (1883). Galton was the founder of eugenics (Starker, 1985, p. 93), and a cousin of Charles Darwin as well (Shepard, 1978, p. 139). In his study of mental imagery, Galton (1883) included numerous reported instances of mental imagery, all in anecdotal form. His survey of friends, all accomplished men and including a number of distinguished scientists, produced results that were quite surprising to him: "I found that the great majority of the men of science to which I first applied protested that mental imagery was unknown to them" (Galton, 1883, p. 58).

Like the Ancient Greek philosophers, Galton believed that images were intrinsic to human thought. His convictions were so unshakable that he refused to accept the initial response to his inquiry. He retorted that "They had a mental deficiency of which they were unaware, and naturally enough supposed that those who affirmed they possessed it were romancing" (Galton, 1883, p. 58).

A second survey of one hundred scientists and intellectuals produced responses ranging from reports of no mental imagery whatsoever, to reportedly vivid perceptions of imagery, though only select cases are elaborated and no frequency distributions were cited (Galton, 1883, p. 61). Galton also cites evidence of images he refers to as number forms (Galton, 1883, pp. 79-105) and color associations (Galton, 1883, pp. 105-12) which belong to the somewhat rare type of mental imagery associated with synaesthesia experiences.

Although, strangely enough, Galton does not refer to him, in 1816 John Herschel described personal experiences that bear a close relationship to Galton's number forms category.

> They consist in the involuntary production of visual impressions, into which geometrical regularity of form enters as the leading character, and that, under circumstances which altogether preclude any explanation drawn from a possible regularity of structure in the retina or optic nerve . . . They are evidently not dreams. The mind is not dormant, but active and conscious of the direction of its thoughts; these things, by calling attention to themselves, *direct* the train of thought into

a channel it would not have taken of itself . . . If it be true that the conception of a regular geometric pattern implies the exercise of thought and intelligence, it would almost seem that in such cases as those above adduced we have evidence of a *thought*, an intelligence, working within our own organization distinct from that of our own personality (Herschel, 1816; in Myers, 1920, p. 56; see Shepard, 1978, p. 143-4).

Herschel never suggested that the reported geometric images resulted in any significant discoveries, that is, beyond the recognition of this phenomenon itself.

3.3.2 F. W. H. Myers

After Galton, Myers was one of the earliest writers to present reported accounts of mental imagery. Myers defined mental imagery in general as the "entencephalic sensory faculty" (Myers, 1920, p. 72), but then in my opinion he unnecessarily limits his discussion by referring to imagery as "internal vision" (Myers, 1920, p. 141), stressing the visual at the expense of the other modalities. Myers is credited with having introduced the term hypnopompic imagery to distinguish those images that are perceived in the transitional state from sleeping to waking up, in contrast with hypnagogic imagery, indicating the transitional state between waking and falling asleep. Hypnopompic imagery occurs "at the moment when slumber is departing . . . a figure which has formed part of a dream continues to be seen as a hallucination for some moments after waking" (Myers, 1892, p. 335).

Myers also identified a type of imagery he called imagination imagery. He wrote,

> I give the name of imagination images to those conscious recombinations of our store of visual imagery which we compose either for our mere enjoyment, as "waking dreams," or as artifices to help us to the better understanding of facts of nature confusedly discerned (Myers, 1920, p. 141).

In addition to hypnopompic and imagination imagery, Myers also identified dream and memory imagery, but sometimes blurred the distinction between the two. At one point he wrote that, "Dreams actually are hallucinations; but they are usually hallucinations of low intensity" (Myers, 1920, p. 142). And at another point he wrote that dreams "consist of confused memory images" (Myers, 1920, p. 141). His categories begin to fall apart under close examination, but they include a useful range of concepts nonetheless.

3.3.3 Richardson

Further precedent for the analysis of imagery by type has been presented by Richardson (1969), who identified four types: after imagery, eidetic imagery, memory imagery, and imagination imagery. Richardson distinguished the types according to the degree of intentional control to which they are subject. Unlike Myers' definition, Richardson uses imagination imagery to refer specifically to hypnagogic and hallucinatory experiences. According to Richardson, after images refer to involuntary response to physical stimuli, like the image of the bright spot that persists after looking into a bright light. As a subset of this category, Richardson produced pulse current images by sending electrical currents into the brain through electrodes affixed to the forehead (Richardson, 1969, p. 112). After images are not considered here because their significance within the scope of scientific discovery is presumably negligible.

Richardson rejects the traditional interpretation of eidetic imagery as photographic in nature. Instead, he favors an interpretation that is less rigid. Kagan and Havemann have defined photographic imagery (1972) as "the ability possessed by a minority of people to 'see' an image that is an exact copy of the original sensory experience." In rebuttal, Richardson states that "no contemporary researchers on eidetic imagery employ exceptional accuracy as one of its defining properties" (Richardson, 1983, p. 22). Richardson defined eidetic imagery, following Jaensch (1923) as the type of vivid memory images that are often experienced by children.

Several other researchers have documented this phenomenon in children; most report that they decreased over time and usually disappeared by early adolescence (Reed, 1988, p. 88; Richardson, 1983, p. 22; McKim, 1980, p. 95; Jaensch, 1923; see also Corliss, 1976). Interestingly, many so-called human calculators were reported to be only in temporary possession of their unique faculties, which frequently faded or disappeared altogether after a few years (Myers, 1920; Galton, 1883). Richardson has also conducted extensive research into the use of imagery to enhance athletic performance (see mental practice below).

3.3.4 McKellar

Like Myers and Richardson, McKellar (1972) outlined several general types of imagery: Dream, memory, hallucinatory, hypnagogic, and hypnopompic. Under the heading of hypnagogic experiences, McKellar identified some less frequently cited examples, including: perseverative imagery, involving the re-experience of repetitive behaviors, such as picking berries, or pulling weeds; and impersonal imagery, which is difficult to describe (even for McKellar), but is related to a sense of unfamiliarity with one's surroundings. Impersonal imagery could potentially benefit problem solving by providing the opportunity to consider a problem in a new, unfamiliar way--in a different light. However, no reports of this nature were found.

McKellar includes a discussion of after sensations, equivalent to Richardson's description of after imagery (Richardson, 1969) presented above. He also presents evidence of mental images involving synaesthesia, citing Galton's earlier interest in this subject. Incidents including both sounds and numbers associated with colors or shapes are cited (McKellar, 1972; Galton, 1883; see also Cytowic, 1989; 1993; cf. Sacks, 1985).

3.3.5 Luria

In *The Mind of a Mnemonist* (1968), Luria reported many types of imagery related to synaesthesia in his mnemonist subject, called simply S., in deference to professional confidentiality. Luria has since revealed his name (see Reed, 1988, p. 88), but it is irrelevant for all intents and purposes here. The subject reportedly possessed a seemingly infinite memory, that was based primarily on the use of visual images. "The only mechanisms he employed were one of the following: either he continued to *see* series of words or numbers which had been presented to him, or he converted these elements into *visual images*" (Luria, 1968, p. 16). The subject did not produce any specifically original scientific discoveries, but the reportedly prodigious nature of his memory, and its visual character, are worth considering.

Luria reported that,

> I simply had to admit that the capacity of his memory *had no distinct limits.* Experiments indicated that he had no difficulty reproducing any lengthy series of words whatever, even though these had originally been presented to him a week, a month, a year, or even many years earlier. In fact, some of these experiments designed to test retention were performed (without his being given any warning) fifteen or sixteen years after the session in which he had originally recalled the words. Yet invariably they were successful. During these test sessions S. would sit with his eyes closed, pause, then comment: "Yes, yes . . . This was a series you gave me once when we were in your apartment . . . You were sitting at the table and I at the rocking chair . . . You were wearing a gray suit and you looked at me like this . . . Now, then, I can see you saying . . . " and with that he would reel off the series precisely as I had given it to him at the earlier session. If one takes into the account that S. had by then become a well known mnemonist, who had to remember hundreds and thousands of series, the feat seems even more remarkable (Luria, 1968, pp. 11-12).

Although Luria's description suggests S.'s memory involved both visual and auditory imagery, it is interesting that he recorded S. as having said "I see you saying." In another passage Luria further emphasizes the visual character of S.'s reported ability:

> S. told us that he continued *to see* the table (of numbers) which had been written on the blackboard or a sheet of paper, that he merely had to "read it off," successively enumerating the numbers or letters it contained. Hence, it generally made no difference to him whether he "read" the table from the beginning or the end, whether he listed the elements that formed the vertical or the diagonal the groups, or "read off" numbers that formed the horizontal rows.
>
> S. continued to see the numbers he had "imprinted" in his memory just as they had appeared on the board or the sheet of paper: the numbers presented exactly the same configuration they had as written, so that if one of the numbers had not been written distinctly, S. was liable to "misread" it, to take a 3 for an 8, for example, or a 4 for a 9.
>
> S. had remarked on a number of occasions that if the examiner said something during the experiment--if, for example, he said "yes" to confirm S. had reproduced the material correctly or "no" to indicate he had made a mistake--a blur would appear on the table and would spread and block off the numbers, so that S. in his mind would be forced to "shift" the table over, away from the blurred section that was covering it. The same thing happened if he heard noise in the auditorium; this was immediately converted into "puffs of steam" or "splashes" which made it more difficult for him to read (Luria, 1968, pp. 20-21).

Corliss also reported several cases involving this seemingly photographic memory phenomenon (Corliss, 1976, pp. 167-84). Luria considered his own research on S. to be significant, however, he reported no specific discoveries to have resulted from S.'s reported abilities.

3.4 Creative visualization

Imagery has been used as a meditative technique in Tantric yoga, as well as Buddhism and Hinduism for over a thousand years.

> A person studying Tantrism is taught to visualize a divine image, to construct it mentally or, more precisely, to project it on a sort of inner screen through an act of creative imagination. It is a question of awakening one's inner forces, yet at the same time maintaining perfect lucidity and self-control (Eliade, 1958, pp. 207-8; in Samuels & Samuels, 1975, p. 23).

Mental imagery has received growing popular interest in recent years. Part of this attention derives from spiritualist interest in the subject. Shakti Gawain has written that,

> In creative visualization you use your imagination to create a clear image of something you wish to manifest. Then you continue to focus on the idea or picture regularly, giving it positive energy until it becomes objective reality . . . in other words until you actually achieve what you have been visualizing (Gawain, 1978).

Unfortunately, claims as to the effects of mental imagery are often overstated. Techniques such as this seem better suited to issues of personal motivation and self-esteem, although these are critical ingredients in the creative process. However, a growing body of evidence suggests that this type of imagery might be more effective than many of us are inclined to believe (see mental practice; and mental imagery in healing below).

3.5 Mental practice

Galton described a technique used by one teacher to facilitate the development of imagery skills among his students.

> He trained his pupils with extraordinary success, beginning with the simplest figures. They were made to study

the models thoroughly before they tried to draw them from memory. One favorite expedient was to associate the sight memory with the muscular memory, by making his pupils follow at a distance the outlines of the figures with a pencil held in their hands. After three or four months' practice, their visual memory became greatly strengthened. They had no difficulty in summoning images at will, in holding them steady, and in drawing them (Galton, 1883, p. 73).

Several researchers have reported promising results in the improvement of motor performance after mental practice (Corbin, 1972; Oxendine, 1968; Richardson, 1967a, b). Richardson found statistical evidence that the practice of mental imagery improved overall performance among a group of athletes. In fact, most professional athletes practice some form of mental imagery to improve their performance (Richardson, 1969). Mental practice has itself become a valuable skill requiring attention and development. Suinn wrote that "The value of mental practice is influenced by the subject's level of skill in the mental process itself" (Suinn, 1983, p. 510). Suinn wrote further that,

> Jean Claude Killy reports that the only preparation he had for one race was to mentally ski the course because an injury prevented on-snow practice. He believes that this race turned out to be one of his best performances. Jack Nicklaus first visualizes the ball landing on the green and actually seeing the bounce, then visualizes the arc of the ball in flight, and then his swing and the ball leaving the ground. His final step is to link these together in proper sequence: visualizing the swing; the ball's trajectory; and its landing and bouncing on the green. Dwight Stones is identified by his pre jump preparation, during which his head can be seen bobbing up and down in rhythm with his mental image of himself approaching and clearing the bar. Chris Everet Lloyd centers on anticipating her opponent's strategy and style and visualizes herself countering with her own attack (Suinn, 1983, pp. 514-15).

3.6 Mental imagery in healing

Paracelsus, a sixteenth century physician from Switzerland wrote "The power of the imagination is a great factor in medicine. It may produce diseases in man and it may cure them" (Hartmann, 1973, p. 129; in Samuels & Samuels, p. 33).

In contemporary times, Bill Moyers recently reported, through a series of interviews with both doctors and patients, on the potential of the mind to influence the healing process (1993). Moyers presented evidence to suggest that mental imagery can play a significant role in the bodies own healing process. Dr. Remen said,

> What we imagine, we experience, and what we imagine affects us. It affects our immune system, and our strength, and our optimism. So we need to take control of our imagination and use it for our well-being. . . .
>
> Imagery is the way the mind and body talk to each other. That's why Olympic athletes often have imagery coaches to help them to imagine their optimal performance and thus improve their actual performance. . . .
>
> Images are the primal language. Maybe the first way we experience the world is through images. And images bring back the old memories and feelings. . . .
>
> My sense is that creativity and healing are very close to each other, in some way that I really could not say more about (Moyers, 1993, pp. 347-48).

3.7 Stages in the creative process

Several stages in the creative process have been identified variously by different authors (cf. Wallas, 1926; Murphy, 1947; Edwards, 1986, p. 47). The majority of theories follow a roughly standard sequence involving some or all of the stages listed below:

1) First Insight is the initial recognition of a problem or a question. Although this description characterizes the earliest stage in the creative process, it can be the most important. Einstein wrote, "The formulation of a problem is often more essential than its solution" (1938). The term was coined in the 1960's by Kneller to describe Getzels' identification of a preliminary questioning process, preceding the investigation of the subject (Kneller, 1965; Getzels, 1980). The choice of the word "insight" suggests a visual metaphor, which is perhaps misleading because this stage is not limited to the visual modality. The first insight is simply an initial idea, irrespective of imagistic content.

2) Saturation is the process of immersing one's self in the material. This is the stage for research and development. This stage, along with incubation and illumination were coined by Helmholtz in the late nineteenth century (1896b). Helmholtz described saturation as the first stage in his creative process. Because mastering a discipline is a lifelong process without a definite starting point, it is understandable that Helmholtz recognized this as the first stage in the creative process. The realization of a significant insight to a significant problem or question is highly unlikely without some initial degree of familiarity with the subject, though perhaps that would constitute a pre-insight saturation phase.

3) Incubation is the process of considering the material after sufficient data have been collected. Incubation is a more reflective process than saturation, and, according to Helmholtz, represents the interim between saturation and illumination.

4) Illumination is realization of the solution: the point at which the question is answered or the problem is solved. It is the experience Archimedes acknowledged with his famous exclamation "Eureka" (I have found it). While the other stages are indeterminate in duration, most writers, including Helmholtz who first identified this stage, describe the process of illumination as a brief or sudden experience, or the moment of discovery. As with insight, the

application of the word illumination suggests a connection to visual imagery. Although this study is concerned specifically with imagery in creative problem solving, imagery is certainly not indicated by every creative act. The visually oriented words used to describe these processes reflects a predisposition to visual imagery deriving either from the writers, or the language, or possibly a combination of both.

5) Verification is the process of checking the results for errors, and possibly confirming them through (objective) observation. Although verification necessarily occurs after illumination, and is the confirmation that a creative discovery has occurred. Until the verification, only the subjects themselves have any awareness that the results are creative and/or productive. The verification stage was first identified by Poincare (1908; see Poincare under secondary below).

According to the data collected for this study, the time span involved in each stage of the creative varies dramatically between the reported incidents. Some reports suggest the entire process occurred in an almost instantaneous way. Others indicate that the stages developed slowly, over long periods of time. The stages represent a useful concept, but the sequence may in reality not be as rigid as it seems. Helmholtz's description of saturation as the initial process, as opposed to first insight, has some merit. Perhaps a pre-insight saturation process precedes the first insight, which is in turn followed by a second saturation stage. Although Helmholtz posits incubation as the reflective analysis *following* saturation, there is necessarily some measure of ongoing deliberation and reflection (incubation) involved *during* the saturation process. Furthermore, if saturation precedes insight, perhaps a pre-insight incubation stage is indicated as well.

Although there are limitations to the staged conception of the creative process, they represent a useful guideline with which to begin. This study will determine, insofar as may be determined from the data, the stage in the creative process at which the reported incidents of mental imagery occurred.

Chapter 4

4.1 Data and Analysis

The data are divided into two sections: primary, and secondary. The primary data represent the core evidence of mental imagery reported in conjunction with scientific discoveries. The analysis of the primary data is the main focus of this study, however, research revealed a number of other incidents that, although they failed to meet the primary selection criteria, nevertheless they further elucidate certain aspects mental imagery in creative problem solving that are both valuable to this research and closely related to the primary data. The secondary data include incidents from the sciences that were insufficiently documented and/or elaborated to warrant inclusion in the primary set, as well as incidents from the arts and humanities (painters, poets and composers as I refer to them below), where the products are far more subjective, at least in a cultural sense than scientific discoveries, which must carry universal application or they are invalid. Although they are not included in the primary data, which is the main body of evidence, they are considered here because they each help to illustrate certain aspects of mental imagery.

With respect to the difference between scientific and artistic production, Richard Feynman (see primary data below), has written that:

> Scientific creativity is imagination in a straitjacket. The whole question of imagination in science is often misunderstood by people in other disciplines. They overlook the fact that whatever we are *allowed* to imagine in science must be *consistent with everything else we know*.... (Scientific discoveries are) not just some happy thoughts which we are free to make as we wish, but ideas which must be

> consistent with all the laws of physics we know. We can't allow ourselves to seriously imagine things which are obviously contradictory to the known laws of nature. And so our kind of imagination is quite a difficult game. . . . Our imagination is stretched to the utmost, not, as in fiction, to imagine things which are not really there, but just to comprehend those things which *are* there (Gleick, 1992, pp. 324-5).

4.2 Data selection criteria

The primary data were selected according to the following criteria:

First, the incident had to involve a report of mental imagery in conjunction with creative problem solving. Incidents involving imagery not associated with scientific discoveries or inventions are presented in the secondary data. Reports of mental imagery in conjunction with artistic production (9 in total) are also included in the secondary data set. These cases are included because they help to illustrate the depth and scope of mental imagery in creative problem solving, as well as its importance.

Second, the incidents had to involve a first person report, though sometimes statements by colleagues or biographers are included as supporting evidence. Because mental imagery is a purely cognitive phenomenon, first person accounts provided the most persuasive evidence that mental imagery had actually occurred. However, citations from respected scientists, researchers in the field of mental imagery, and/or eminent historians were accepted for the secondary data. In many cases, multiple citations are recorded in the literature.

Third, there needed to be enough details included in the descriptions to provide some sense of the content of the reported imagery and the modality in which it occurred. The content and modality of the reported imagery, as well as the circumstances surrounding it provide the material by which the incidents are analyzed. Furthermore, they help to substantiate the report that mental images were involved.

Fourth, the incident must have resulted in scientifically verifiable results. This ensured that the incidents represented unquestionably creative behaviors. The primary data is limited to incidents of scientific discovery and/or invention. This decision is based on the presumption that scientific discoveries are objectively and universally recognizable (or they are invalid), whereas the products of artistic creativity are subjective and culture bound.

4.3 Primary Data: First Person Accounts

This first group of data are organized according to a roughly chronological sequence; in some cases the chronological order has been violated in order to group cases according to similarities with respect to either the specific imagery or the nature of the research involved. Immediately following the data are analyses of the cause and function of the reported imagery, as outlined in the introduction.

4.3.1 Oliver Evans

Ferguson (1977; 1992) cites the case of Oliver Evans who, in the 1870's, invented the automatic flour mill. Evans reported that:

> The arrangement I so far completed (in my mind) before I began (to build) my mill that I have in my bed viewed the whole operation with much mental anxiety . . . from the time the wheat is emitted from the wagon until it is completely manufactured into superfine flour the whole is done by machinery without any part thereof being moved by manual labor (Ferguson, 1977, p. 834; 1992, p. 47; see Starker, 1985, p. 93; cf. Shepard, 1978, p. 141).

The incident reportedly occurred while Evans was lying in bed. Evans' position (lying down), and location (in bed) are presumably highly conducive to comfort and relaxation. Generally speaking, lying down is the position that allows the muscles to relax the most completely. Being in bed by his own account, there must have been some measure of padding and/or insulation under him, if only straw. These factors may have contributed to his state of mind, possibly facilitating the flow of ideas, or in this case the (reported) flow of images. It is unclear from the description whether the reported "mental anxiety" was perceived as a positive or a negative factor. His anxiety seems unrelated to any apparent cause and there is no suggestion that he was asleep or dreaming at the time, which might have accounted for such feelings. Nevertheless, it is interesting to note that the reported imagery was accompanied by this affective element.

Evans' report of having "viewed" the operation suggests visual imagery was involved. His description of the (automatic) handling and transportation of wheat throughout the milling process also suggests visual imagery. This is not surprising considering that the design was probably best adapted to pictorial means of representation. There are no indications of other modalities involved.

There is a silent implication in the presentation of this account that this was the first time Evans had considered a pictorial representation of his mill, but this is in fact unknown. It is not clear whether any drawings, or even mental images had been considered prior to this reported experience. Possibly drawings for the mill had already been drafted, and this was simply the first time that Evans had perceived mental imagery in connection with the mill. The statement begins, "The arrangement I so far completed in my mind." Evans did not report on the means by which he had arrived at that arrangement. The imagery he reported was involved specifically in "viewing the operation," but this seems to have occurred at an advanced stage in the creative process, perhaps after the design had been completed. Evans' description that the arrangement was so far completed suggests that although it had been substantially developed, perhaps it was not entirely completed at the time of the reported imagery. On the other hand, he reported to have viewed "the whole operation," suggesting that the imagery encompassed every aspect of the automatic mill, and that the design was at least approaching completion.

The reported imagery seems to have occurred at an advanced stage in the creative process, after the overall plan had already been established. There is some ambiguity as to whether imagery was involved in the development process or not. The reported imagery was not specifically related to the process of developing the idea as much as it was itself a byproduct of Evans' involvement in that process. The reported imagery may have simply provided a reflection of his plan and nothing more; though his tone suggests it may have provided some degree of affirmation (verification), at least for Evans himself. If this was in fact the first time Evans had conceived of the mill in pictorial terms, then perhaps the imagery provided some degree of illumination as to the completed design as well.

There is no record of other incidents of mental imagery involving Evans, and it is not apparent from the report whether he was suggesting that the reported imagery was an isolated incident, or if there may have been other related experiences leading up to or subsequent to this event.

4.3.2 James Nasmyth

According to Nasmyth's report, also provided by Ferguson, mental imagery was reportedly perceived in conjunction with his invention of the steam pile driver.

> In describing the origin of his steam pile driver, James Nasmyth, a mid-nineteenth-century English engineer, said that the machine "was in my mind's eye long before I saw it in action." He explained that he could "build up in the mind the mechanical structures and set them to work in imagination, and observe beforehand the various details performing the

respective functions, as if they were in absolute material form and action" (from Ferguson, 1992, p. 49; Nasmyth, 1883, p. 272).

Although this account is embellished by Ferguson, Nasmyth himself reported that imagery was involved. Nasmyth reported that the machine was in his mind's eye, and also that he was able to observe it in his imagination. These remarks further suggest that the reported imagery was perceived in the visual mode, as does his reference to the mechanical structures represented by the imagery. Nasmyth's report that he observed the "mechanical structures performing the respective functions" suggests that the imagery was kinetic. No other modalities were indicated.

Nasmyth's description of having perceived the mechanical structures "as if they were in absolute material form and action" seems to refer more specifically to the accuracy with which the imagery represented the respective functions those structures were to perform, as opposed to a confusion concerning the reality of the perceptions or the objects contained therein. Nasmyth seemed to recognize all along that he was perceiving mental images, or as he put it, products of the "imagination." His description of the images as having a "material" quality may be a reference to their pictorial quality, suggesting that they represented objects as seen in the real world, as opposed to diagrammatic schema or blueprints, which represent only the conceptual design and not the way the finished product would look. His description suggests that the images represented the operation of the machine as if they had been observed in the real world.

Nasmyth's report that could "build up in the mind the mechanical structures" is somewhat ambiguous. It could be a reference to the construction (building) of mental imagery to represent the machine; or it could suggest that mental imagery was involved in the development of the design for the machine. If mental imagery was involved in the development process, that could indicate it was part of the saturation stage. On the other hand, if mental images were exclusively a way to "observe" the completed design before the machine was built, then the incubation stage in indicated. Furthermore, as with Evan's case (above), Nasmyth's report seems to suggest that the imagery provided a certain degree of confirmation or verification for his design as well. There is no indication that mental imagery was involved in the illumination or first insight.

Although it is unclear whether or not this report represents an isolated event, Nasmyth's report that this imagery "was in my mind's eye long before I saw it in action" leaves open the possibility that this was not a one time isolated event, but perhaps had occurred several times within the context of this invention. Nevertheless, there are no other reports of mental imagery involving Nasmyth, and there is no further indication as to circumstances that may have facilitated this experience or its role in the creative process.

4.3.3 James Watt, part 1

James Watt, the Scottish inventor, is credited with revolutionizing the steam engine. Watt reported that the design to improve the efficiency of the steam engine occurred to him as a mental image, during an evening walk.

> It was in the Green of Glasgow. I had just gone to take a walk on a fine Sabbath afternoon. I had entered the Green by the gate at Charlotte Street--had passed the old washing house. I was thinking upon the engine . . . and gone so far as the Herd's House, when the idea came into my mind that as steam was an elastic body it would rush into a vacuum, and if a communication was made between the cylinder and an exhausted vessel, it would rush into it and might be there condensed without cooling the cylinder. I then saw that I must get quit of the condensed steam and injection water. Two ways of doing this occurred to me. First the water might run off by a descending pipe, if an outlet could be got at a depth of 35 or 36 feet, and any air might be extracted by a small pump, the

> second was to make the pump large enough to extract both water and air . . . I had not walked further than the Golf House when the whole thing was arranged in my mind (Thurston, 1878, p. 87-8; see Montmasson, 1932, pp. 176-7; cf. Shepard, 1978, p. 141).

There is something about the act of walking itself that relieves stress and promotes relaxation, possibly related to the physical exertion involved and maybe to the prolonged repetition of movement as well. Furthermore, Watt was outdoors in "the Green of Glasgow," and the unique scenery around him, or even the change of scenery alone could have contributed, along with the act of walking, to an auspicious state of mind. Watt's recognition that it was the Sabbath, a religious day of rest, suggests that he may have been observing that tradition by taking a walk. There is also a possibility that Watt may have taken the walk expressly for the purpose of stimulating his thinking processes, because he reported to have been specifically thinking about the engine at about the time when he entered the Green. This was a problem he had been working on for some time, yet without apparent success. The act of walking, together with the change of scenery or perhaps the fresh Scottish air could have facilitated his creative process. Watt reported that he had walked an apparently short distance, "as far as the Herd's House, when the idea came into my mind." Did being outdoors stimulate his thinking? Was the change in scenery a necessary diversion? Did the exercise help him to relax? The answer is not apparent; perhaps all three possibilities apply.

The exact point in the creative process at which mental imagery became involved is unclear. His description of the incident begins with, as he says, an "idea." An idea does not necessarily suggest the perception of mental imagery; however, as he continued to describe the idea in detail he begins to suggest imagery more strongly. Watt's description of steam as <u>elastic</u>, and that it would <u>rush</u> into a vacuum, suggest that spatial relationships, ergo visual imagery (pictorial representation) were involved, and perhaps is an indicator that kinesthetic associations were involved. Watt may have perceived the expansion of the steam not only in a visual but perhaps also in a physical (tactile/kinesthetic) way. He was reportedly able to implement this knowledge by applying it to the design of the engine immediately. Watt's description of a "communication between a cylinder and an exhausted vessel," seems to refer to either a pictorial or diagrammatic representation of some part of the engine, perceived as a mental image. Watt's report involves the intentional control and manipulation of imagery. Only the idea, which itself may have been non-imagistic, seems to have occurred spontaneously, or should I say suddenly because he was admittedly thinking about the problem shortly prior to the realization of the idea.

When Watt wrote that, "I then saw that I must get quit of the condensed steam" he may have been describing perceptions of mental imagery in the visual mode. But there is also a possibility that he used the phrase metaphorically as the recognition of an abstract impediment (between himself and the solution). This choice of words is a bit confusion and tends to obscure the imagistic feature of his reported experience. However, the way Watt continued to describe the descending pipe for run off, specifying the exact depth of the outlet at 35 or 36 feet, there is again a strong suggestion that mental images were involved. The final confirmation occurs in the last sentence where Watt wrote, "the whole thing was arranged in my mind." The arrangement of cylinders, vessels, pipes, outlets and pumps, and the flow of steam water and air through them is an engineering problem that necessitates a diagrammatic solution. The remarkable feature is that Watt reported to have designed the solution with mental images.

This invention was perhaps Watt's most important contribution and he did convey a certain of degree of surprise at the short time period involved. Yet, he described the reported perception of mental imagery as if it were an entirely familiar aspect of his thought processes. Although there is another incident concerning Watt in which mental imagery was reportedly involved (see Watt, part 2 under second hand accounts below), that report was not reported by Watt, and he made no statement concerning the frequency of these reported perceptions. Nevertheless, his nonchalant attitude suggests that mental imagery was not altogether unfamiliar to him.

Watt had been working on this problem for some time before this reported incident, indicating both that, 1) he had identified a problem or an area in need of improvement, representing the first insight, and 2) he had saturated himself in the issues involved. These are considered to be the two first stages in the creative process and the report suggests they occurred prior to the reported incident. Watt's description focuses entirely on his experience of the moment of discovery, or the moment of illumination. Watt suggested that this experience occurred over the relatively short period of time, during which he was taking a walk, but there seem to be several distinct stages within this illuminating experience as well. The idea that first came to Watt, "as steam was an elastic body . . ." seems to have provided the insight to the solution, but not the completed design. There was some necessary experimentation involving the consideration of two alternate methods to "get quit" of the water, which he reported to have performed in his mind and with apparent facility. Finally he is confident he has the solution and the whole thing arranged. The illuminating experience itself seems to have involved its own micro creative process, including a moment of insight where he gets the idea, an experimental (saturation/incubation) phase where he considered alternate possibilities, then finally arriving at a solution. Watt seemed to have been convinced he had found the solution on the basis of the reported imagery, suggesting it may have provided the verification as well, at least on some personal level.

Watt's report suggests that several distinct stages were involved in his illuminating experience. Visual imagery was possibly involved in the first insight, but is more clearly indicated in conjunction with the developmental and realization of the micro processes contained within the illumination stage, and also as a method of verification.

4.3.4 Dimitri Mendeleev

Mendeleev reported that his discovery of the Periodic Table of the Elements occurred while he was asleep.

> Mendeleev went to bed exhausted after struggling to conceptualize a way to categorize the elements based on their atomic weights. He reported, "I saw in a dream a table where all the elements fell into place as required. Awakening, I immediately wrote it down on a piece of paper. Only in one place did a correction later seem necessary." In this manner, Mendeleev's Periodic Table of the Elements was created (Krippner, 1972; from Gowan, 1977, p. 85; see Arieti, 1976, pp. 273-4; Goldberg, 1983, p. 77; Starker, 1985, p. 92).

Mendeleev's description of what he reportedly "saw" in his dream, "a table where all the elements fell into place," suggests that the experience involved mental imagery in the visual mode. The reference to a table does not necessarily indicate the image of a piece of furniture. A table is also a graphic (pictorial) representation of information according to rows and columns, which is exactly the way he organized the elements, reportedly in the dream. This second definition is more consistent with the content Mendeleev described. Nevertheless, a table is a spatial arrangement. A table can contain verbal data, numbers, words, etc., however the arrangement itself is nonverbal. The primary contribution of the periodic table is that it arranges the elements into rows and columns according to related groups. The physical properties of the elements precisely predetermine their position in the table. The spatial arrangement is the essential feature of the table and requires a graphic representation.

Mendeleev did not say if the elements themselves were associated with a visual form in the reported dream, but he did report that they "all fell into place". Mendeleev may have used the verb "to fall" in the literal sense to indicate that the elements were perceived to have fallen onto the table, but more likely he used the term figuratively to indicate simply that the elements (or numbers, symbols, whatever they were perceived as) appeared in exactly the correct position on the table. In either case, there is no suggestion that he directed or changed the reported imagery in any way. He simply observed the reported dream as it spontaneously occurred. His admission that "in one place a correction later seemed necessary" indicates a relatively minor imperfection. His recognition of that flaw seems to add credibility to his testimony.

The report that Mendeleev had been struggling with this problem previously suggests that he had already entered the saturation and/or incubation stage. His report that he discovered the solution in virtually its completed form while he was asleep suggests that it was the reported mental imagery (dream) that represented the solution, or rather the illumination of the discovery. Possibly some degree of verification was involved as well, although the report suggests that he was not entirely convinced until he had awakened and wrote it down. There is no reference to a first insight.

The report that the solution was discovered in a dream while Mendeleev was asleep suggests that all the necessary information had already been collected before going to sleep. He also seems to suggest that even as the imagery occurred he recognized that the elements were positioned in the proper places: they fell into place as required. This suggests that Mendeleev already knew the positioning requirements before he fell asleep. Perhaps the exhaustion and struggle, as Krippner described it, of his work on this problem prevented him from putting together the information already at his disposal. Sleep may have provided him with some necessary distance, so that as soon as the problem came up again, even while he was sleeping he was able to recognize what he already knew but had been unable to identify before.

Krippner reported that "Mendeleev went to bed exhausted after struggling" with this problem in particular. Being exhausted may have contributed to an especially deep sleep, and possibly to active dreaming episodes. Rarely have people reported dreams entirely devoid of imagery in any modality. Mendeleev may have been thinking about the problem at or around the time he fell asleep. His deep involvement in this problem, and his thoughts leading up to the moment that sleep began could have contributed the imagery he reported to have perceived in the dream. The imagery that reportedly occurred during his dream provided the solution (illumination) to the problem, and in essentially its completed form. This was apparently an isolated incident.

Mendeleev's reported dream imagery was all the more remarkable considering it accommodated several elements that had yet to be discovered:

> When Mendeleev dreamed the atomic order of the elements, he left a hole, where later helium was discovered (or rather posited), and still later his open-ended model had places for all the radioactive and trans-uranium elements such as plutonium (Gowan, 1977, p. 85; cf. Arieti, 1976, p. 274 ff.; Starker, 1985, p, 92).

According to Arieti, the arrangement of Mendeleev's table further predicted weights for certain elements that were more precise than measurements up until that time had revealed:

> In several cases the accepted atomic weight of some elements did not correspond to that anticipated by the periodic law. He challenged the correctness of those atomic weights and subsequent investigations proved that he was right (Arieti, 1976, p. 274).

This evidence is indicative of the fact that Mendeleev's Periodic Table of the Elements follows an underlying pattern or organizational principle that must be intrinsic to the structure of the elements themselves. Mendeleev's model somehow reflected that natural structure in an iconic way, preserving their intrinsic characteristics and resulting in the accommodation of new, unanticipated elements that had yet to be discovered, as well as predictions for improved measurements.

James Gleick, author of a biography on Feynman (1992), wrote, "In part, the process of scientific visualization is a process of putting one's self *in* nature" (Gleick, 1992, p. 244).

And Thomas Huxley wrote, "The genesis of a visual representation is that fashioning by Nature of a picture of herself, in the mind of man, which we call the progress of science" (Huxley, 1869, p. 10; from Robin, 1992, p. 20).

4.3.5 Herman Hilprecht

This case, once more involving dream imagery, was reported by Herman Hilprecht (in Myers, 1920, pp. 80-3), an Assyriologist and professor at the University of Pennsylvania. While this example is not as eminent as many of the other cases included in this study, it is a remarkable incident involving a discovery reported to have resulted from the perception of mental imagery in the context of a dream. This is perhaps one of the least eminent discoveries included here in terms of the significance of the results; however, it describes a reported mental imagery experience in such clear and elaborate detail that it warrants consideration.

> One Saturday evening, about the middle of March, 1893, I had been wearying myself, as I had done so often in the weeks preceding, in vain attempt to decipher two small fragments of agate which were supposed to belong to the finger-rings of some Babylonian. The labor was much increased by the fact that the fragments presented remnants only of characters and lines, that dozens of similar small fragments had been found in the ruins of the temple of Bel at Nippur with which nothing could be done, that in this case furthermore I had never had the originals before me, but only a hasty sketch made by one of the members of the expedition sent by the University of

Pennsylvania to Babylonia. I could not say more than that the fragments, taking into consideration the place in which they were found and the peculiar characteristics of the cuneiform characters preserved upon them, sprang from the Cassite period of Babylonian history (circa 1700-1140 B.C.); moreover, as the first character of the third line of the first fragment seemed to be KU, I ascribed this fragment, with an interrogation point, to King Kurigalzu, while I placed the other fragment, as unclassifiable, with other Cassite fragments upon a page of my book where I published the unclassifiable fragments. The proofs already lay before me, but I was far from satisfied. The whole problem passed yet again through my mind that March evening before I placed my mark of approval under the last correction in the book. Even then I had come to no conclusion. About midnight, weary and exhausted, I went to bed and was soon in deep sleep. Then I dreamed the following remarkable dream. A tall, thin priest of the old pre-Christian Nippur, about forty years of age and clad in a single abba, led me to the treasure-chamber of the temple, on its south-east side. He went with me into a small, low room, without windows, in which there was a large wooden chest, while scraps of agate and lapis-lazuli lay scattered on the floor. Here he addressed me as follows: "The two fragments which you have published separately upon pages 22 and 26, belong together, are not finger-rings, and their history is as follows: King Kurigalzu (circa 1300 B.C.) once sent to the temple of Bel, among other articles of agate and lapis-lazuli, an inscribed votive cylinder of agate. Then we priests suddenly received the command to make for the statue of the god Ninib a pair of earrings of agate. We were in great dismay, since there was no agate as raw material at hand. In order to execute the command there was nothing for us to do but to cut the votive cylinder into three parts, thus making three rings, each of which contained a portion of the original inscription. The first two rings served as earrings for the statue of the god; the two fragments which have given you so much trouble are portions of them. If you will put the two together you will have confirmation of my words. But the third ring you have not yet found in the course of your excavations, and you never will find it." With this, the priest disappeared. I awoke at once and immediately told my wife the dream that I might not forget it. Next morning--Sunday--I examined the fragments once more in the light of these disclosures, and to my astonishment found all the details of the dream precisely verified in so far as the means of verification were in my hands. The original inscription read: "To the god Ninib, son of Bel, his lord, has Kurigalzu, pontifex of Bel, presented this." The problem was thus at last solved (Myers, 1920, pp. 80-82).

Mental imagery is indicated extensively throughout Hilprecht's report. The way the priest is described: tall, thin, forty years old and dressed in an apparently ancient style of clothing, suggests that perceptions of mental imagery in the visual modality were involved. The reported image of being led through a temple to the treasure chamber, described as a "small, low room without windows," further suggests the visual mode, as do the descriptions of objects that were perceived to be in the room: "a large wooden chest" and "scraps of agate and lapis lazuli." The narrative story reportedly spoken by the priest in the dream suggests that auditory imagery was perceived as well. It was the reported verbal narration that reportedly carried the part of the dream that reportedly revealed the discovery connecting the stone fragments. The specific discovery seems to have been more closely related to the reported auditory images than to the visual images that Hilprecht described.

Myers reported that "Hilprecht is unable to say what language the old priest used in addressing him. He is quite certain it was not Assyrian, and thinks it was either English or German" (Myers, 1920, p. 83). The use of auditory images in scientific discovery is also indicated by Howe (see above), but reports such as these are rare in the context of scientific discovery, so far as this study has revealed (see poets below). Presumably, dream images are often accompanied by auditory images, but few other references to specifically auditory images were found (see Coleridge and composers below).

The narration (auditory imagery) attributed to the priest in the reported dream revealed the connection between the broken fragments in a strikingly direct and complete manner. The priest reportedly told Hilprecht not only the story behind the connection between two fragments, in great detail, but also the page numbers on which sketches of those fragments were arranged to be published in an article. This is somewhat ironic considering Hilprecht's report suggests he perceived the source of the discovery (the narration of the priest) in the dream as disassociated with his own identity. Hilprecht had been working on the publication up until that very night when he had the reported dream, and the report that the dream included specific page numbers for the fragments suggests that he may simply have memorized the entire article. It is not beyond reason to suspect that Hilprecht could have identified every object according to the page on which it appeared. However, the reference to those specific artifacts in the reported dream could also suggest that he had previously registered some special significance about them, either individually or as a pair, possibly because they both had a circular form with corresponding diameters.

Although Hilprecht wrote that he was in a "deep sleep" at the time the dream reportedly occurred, his report that he "awoke at once" suggests that he was nevertheless conscious of the dream's significance even as it occurred, like Howe and Mendeleev. Reportedly, no further investigation was required; Hilprecht only needed to verify the connection, which he did, adjusting his manuscript accordingly. The completeness with which Hilprecht discovered this solution in the dream suggests that he already had all the necessary information at his disposal before going to sleep that night. His report suggests that the act of dreaming precipitated his recognition of the discovery, the moment of illumination.

The report is all the more remarkable considering the incident was reported to have occurred before Hilprecht had actually seen the objects, which had then only recently been placed in the Imperial Museum in Constantinople. Hilprecht had seen only drawings of the objects, which he described as "hasty sketches." Hilprecht reported that, "According to the memoranda in our possession, the fragments were of different colors, and therefore could have scarcely belonged to the same object" (Myers, 1920, p. 82; see Starker, 1985, p. 92).

Yet, the drawings could have been in black and white, which may have suggested a visual correspondence even though this correspondence was contradicted by the verbal report of their respective coloration. In August of the same year, 1893, Hilprecht traveled to Constantinople to examine the fragments in person for the first time.

> It was to me a matter of the greatest interest to see for myself the objects which, according to my dream, belonged together, in order to satisfy myself that they had both originally been parts of the same votive cylinder. Halil Bey, the director of the museum, to whom I told my dream, and of whom I asked permission to see the objects, was so interested in the matter, that he at once opened all the cases of the Babylonian section, and requested me to search. Father Scheil, An Assyriologist from Paris, who had examined and arranged the articles before me, had not recognized the fact that these fragments belonged together, and consequently I found one fragment in one case, and the other in a case far away from it. As soon as I found the fragments and put them together, the truth of the dream was demonstrated *ad oculos*--they had, in fact, once belonged to one and the same votive cylinder. As it had been originally a finely veined agate, the stone-cutter's saw had accidentally divided the object in such a way that the whitish vein of the stone appeared only upon the one fragment and the larger gray surface upon the other. Thus I was able to explain the discordant description of the two fragments (Myers, 1920, pp. 82-83).

Hilprecht's account carries an aura of mysticism, partially because the messenger in his dream seemed disassociated with his own identity, and possibly because it concerns dreams and ancient religious artifacts. Nevertheless, Hilprecht's account suggests that he was thoroughly familiar beforehand with virtually every element represented within the reported dream image. The processes that enabled Hilprecht to connect the two fragments from the available descriptions are somewhat mysterious themselves, especially considering that those available descriptions were revealed, in his dream, to be somewhat inaccurate, as in Mendeleev's prophetic dream leading to the correction of certain atomic weights (see Mendeleev above). Furthermore Hilprecht's dream included a reference to a third fragment that, according to the messenger in the dream, "you have not yet found and never will find." This aspect of the dream is even more mysterious, considering no evidence was ever found for the existence of this third fragment.

The solution must have originated in Hilprecht's extensive knowledge of Assyrian culture, and in his attentive observation of the artifacts, or at least of the drawings that were available. However, the solution (illumination) was presented in a strikingly direct manner by the reported dream experience involving visual, but perhaps more significantly in this case auditory imagery.

4.3.6 Friedrich Kekule

The Swiss chemist Friedrich Kekule described two incidents reportedly involving mental imagery that lead up to his discovery of the structure of the benzene molecule. In the first incident, Kekule was riding on a bus during his commute home one evening when he reportedly experienced a mental image.

> One fine summer evening I was returning by the last omnibus through the deserted streets of the metropolis, which are at other times so full of life. I fell into a reverie, and lo! the atoms were gamboling before my eyes. Whenever, hitherto, these diminutive beings had appeared to me, they had always been in motion; but up to that time, I had never been able to discern the nature of their motion. Now, however, I saw how, frequently, two smaller atoms united to form a pair; how a larger one embraced two smaller ones; how still larger ones kept hold of three or even four of the smaller; whilst the whole kept whirling in a giddy dance. I saw how the larger ones formed a chain . . . I spent part of the night putting on paper at least sketches of these dream forms (Findlay, 1948, p. 42; Koestler, 1964, pp. 169-70; see Shepard, 1978, p. 147).

Kekule described several factors that may have contributed to his reported mental imagery. He had spent the day working, and by the time the imagery reportedly occurred it was evening: He may have been tired. He reported that the streets were more deserted than usual so presumably there was also less commotion and fewer distractions. He was sitting down, which is generally a relaxing position even on the hardest of benches. At some point or another, a great many of us have fallen asleep in a sitting position. Kekule further reported he was riding on a bus, and the vibrations from the engine sometimes have a relaxing, almost hypnotic effect. Finally, it was summer, so it was probably warm out. These factors could have facilitated a more relaxed, quiet state of mind, conducive to introspection.

Whatever the specific causes were, Kekule reported that he "fell into a reverie." A reverie is sometimes described as a half sleep, or a waking dream. Webster's defines reverie as "a state of dreamy meditation or fanciful musing; a daydream; a fantastic, visionary, or unpractical idea" (Webster's, 1989, p. 1226), a fascinating aggregate of meanings in itself. Kekule seemed to describe the middle ground that sometimes occurs between wakefulness and sleeping, suggesting specifically a hypnagogic experience. Reports of dream imagery in conjunction with hypnagogic experiences are not uncommon (see Myers above), and the fantastic nature of the imagery Kekule reported further suggests a dream-like experience.

Kekule's reported mental imagery could have been a waking dream resulting from a hypnagogic state, but his description suggests another possibility as well. There is an experience typically referred to as "sparks in the eyes," which is a common experience involving the perception of bright points of light or sparks, often in motion, that are caused by the motion of blood cells through capillaries in the eyes. Sparks in the eyes typically occur after rubbing the eyes, standing up too suddenly, trauma to the head, or anything that causes a sudden increase in blood flow to the head (and eyes). They can also happen when opening the eyes for the first time in the morning. Kekule did not describe the visual appearance of the atoms in detail; he focused on their behavior. However, his description of their behavior is not inconsistent with the perceived motion of sparks in the eyes. Kekule's description of the reported images simply as atoms could indicate that they were perceived as points of light, possibly suggest sparks in the eyes. Because sparks are a relatively common experience, this reading would suggest that: 1) the reported imagery itself was not an unusual phenomenon, and 2) that (as a result of his immersion in this subject) he recognized something relevant to his research in a relatively commonplace experience.

What would a real atom look like if we could see one? Kekule's recognition of the reported images as atoms may have resulted from his ongoing research or scientific background more than the nature of the images themselves. The images Kekule reported, atoms that were "gamboling" and "in a giddy dance," are abstract images that do not represent familiar perceptions, or sights in this case, of the real world; and yet, he understood that in them was a clue to the structure of the benzene molecule, part of the hidden order behind the visible world.

The reported imagery seems to have occurred spontaneously and without any effort. Although he instantly seemed to recognize something important in the images, he reported only to have observed the images as they occurred, without having caused or manipulated the images in any consciously intentional way. In fact, the one feature that seemed to distinguish this reported experience from other previous incidents he reportedly experienced was the ability "to discern the nature of their motion," indicating a non-interactive, purely observational (mental) behavior.

This reported imagery experience seems to have functioned as an inspiration for Kekule to continue work on his research, possibly providing a new direction as well. He reported that he "spent part of the night putting on paper at least sketches of these dream forms," indicating that the experience had deeply excited him to work, and further inspiring him to make sketches as a result. Kekule did not say whether drawing was a regular part of his process or not, but his desire to record the reported imagery in a pictorial, or graphic way suggests that it was the visual aspect of the reported imagery that he recognized as important. The process of drawing, and consequently of actually seeing the images (with his eyes) may have helped Kekule to fix the images more firmly in his mind. Drawing may also have helped Kekule to develop his acuity for those images, enabling him to attend more closely to the imagery he reported to have perceived on subsequent occasions (see below). The diligence with which Kekule recorded his reported imagery through drawing suggests that he suspected a pictorial (or diagrammatic) representation would be involved in the solution to the structure of the benzene molecule. He seemed to have recognized, in a prescient way, some part of that structure in the dream forms he reportedly experienced.

The specific number and chronology of any prior imagery experiences is unknown, but, Kekule clearly indicated that similar mental images had appeared to him before, "Whenever, hitherto, these diminutive beings had appeared to me, they had always been in motion." Shepard notes that over a period of years Kekule had, on occasion, experienced "images of what he took to be atoms dancing before his eyes" (Shepard, 1978, p. 147). Kekule described that the reported experience cited above represented a significant breakthrough in a series of related imagery experiences: "up to that time, I had never been able to discern the nature of their motion." Why Kekule was suddenly abie to discern these features that had eluded him before is unknown, but the way he described the incident it is easy to presume that earlier episodes could have contributed to his facility in observing the reported imagery on this occasion. Kekule considered his improved ability to discern the motion of the reported mental images a milestone in his process of discovery. Those skills may have developed as a result of previous experiences of this type.

It was a number of years later that Kekule revolutionized organic chemistry with the discovery of the benzene structure. He reported that the solution appeared to him during a second, similar experience reportedly involving mental imagery.

> I turned the chair to the fireplace and sank into a reverie. The atoms flitting again before my eyes. This time the smaller groups kept modestly in the background. My mind's 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 if struck by lightning, I awoke; I occupied the rest of the night working out the consequences of the hypothesis (Findlay, 1948, pp. 36-8; from Beveridge, 1961, p. 76; see Koestler, 1964, p. 118; MacKenzie, 1965, p. 135; Burnshaw, 1970, p. 177; Gowan, 1977, pp. 83-4; Shepard, 1978, p. 147; Starker, 1985, pp. 91-2; cf. Krippner & Hughes, 1970, p. 42; Krippner, 1972; Rothenberg, 1979, p. 106; West, 1991, p. 195; Goleman, Kaufman & Ray, 1992, p. 23).

As with the bus ride home after a day of work, these circumstances, sitting at home, in front of the fireplace, are conducive to quiet and introspection, and may have contributed to the self-described state of reverie he reported, which, again suggests a hypnagogic, or falling-asleep experience. As with the experience on the bus, these reported images could have been the result of sparks in his eyes. There is also a possibility that the reported images were the result of actual sparks or ashes emitted by the fire in front of him. There is another possibility that they could have been the result of staring into the fire which can produce a hypnotic effect, sometimes called pareidolia, that is often accompanied by the perception of images. But the fact that Kekule reported these seemingly related experiences both on the bus after work and at home in front of the fire suggests that the causes in both instances were also related. Since neither incident occurred while he was actually in bed where falling asleep would presumably occur most frequently, his reports suggest that there was something unique about those hypnagogic states that he described as reverie that might have caused or facilitated the reported perception of mental imagery. Perhaps being in a quiet, relaxed state of mind, but specifically someplace other than in bed helped to enhance or prolong the hypnagogic state.

It is interesting to observe that hypnagogic states are commonly described by the words "falling asleep." Kekulé described his experience by writing that he "sank into a reverie." In the earlier example he wrote that he "fell into a reverie." In addition to what I have characterized as a quiet, introspective state of mind, these words suggest that, at least for Kekule, hypnagogic experiences may be accompanied by feelings of relinquishing control, or of allowing one's self to submit to natural forces, like gravity. Kekule may have used these words to describe physical sensations associated with those experiences, but he may also have been using the words metaphorically to designate the relinquishing of conscious control over body and mind to sleep. Being asleep is our most helpless, vulnerable state. This attitude seems to be reflected in the language commonly used to describe such states as well as in Kekule's personal account. There is a the suggestion in Kekule's account that the loosening of conscious controls may, at times, allow the mind to drift in ways that may create new, previously unconsidered associations or alternatives.

Kekule's description that the images "whirled scornfully" suggests that he perceived an emotional quality in the images. The scornful quality that Kekule perceived may reflect his own frustration at having worked at the problem for so long without success. This affective quality may have been present in the earlier reported incident where he described the images as "united," "embraced," and "giddy," although those descriptions suggest an entirely different range of emotional qualities that are quite distinct from scorn. Although the reported imagery is closely related in both incidents, the perception of such different affective qualities suggests they do not follow any logical pattern.

Kekule wrote that he "awoke, and spent the night working out the consequences of the hypothesis." It is not entirely clear from his description, but the hypothesis Kekule seems to refer to, although it is unsaid, is that the structure of the benzene molecule is circular (a closed hexagonal ring). This concept was not completely contained within the imagery alone. There was a conceptual leap he made from the observation of the imagery involving "whirling" snake biting its own tail to his scientific hypothesis about the circular structure of benzene. This transition is not accounted for by the reported mental imagery. Kekule's report that thereafter he only needed to work out the consequences suggests that the problem was solved at that moment; however, there seems to be a significant gap between the content of imagery and the solution. Imagery seems to have been the catalyst for his realization of the solution.

Imagery seems to have played a role in facilitating the moment of illumination, reportedly providing a crucial bit of information that enabled him to solve the problem. In the first experience cited above Kekule described that he had recognized some potential significance in the reported imagery, but the primary significance of that experience was that it functioned as practice (or training) for later observations, and possibly as an inspiration to continue his work as well. Kekule wrote, "my mind's eye (was) rendered more acute by repeated visions of this kind," suggesting that repeated imagery experiences had contributed to his reported perception of imagery in this culminating incident. Furthermore, in response to the reported imagery he made sketches; that process could have helped stimulate him to think in pictorial terms. According to his report, mental imagery was a crucial element involved in the illumination of his discovery. Kekule's earlier report of mental imagery may have facilitated the development of his ideas, possibly functioning as an outlet for the incubation stage. Saturation implies a more intentional process that is indicated here. The relinquishing or loosening up of conscious controls may have facilitated unexpected but apparently useful associations to form. There is no indication that imagery was involved in the first insight.

4.3.7 Jacques Hadamard

Jacques Hadamard was a mathematician who has written extensively on the subject of mathematical invention (Hadamard, 1945; see literature review above). Apparently, his interest in this subject stemmed in part from a personal experience where mental imagery was reportedly involved in the solution to a problem. This is the way he described his reported imagery.

> I see a schematic diagram: a square of whose sides only the verticals are drawn and inside of it, four points being the vertices of a rectangle and joined by (barely discernible) diagonals. It seems to me that such was my visualization of the discovery as far as I can recollect (in Rothenberg, 1979, p. 105).

Hadamard admits to limitations in his memory of the experience, but his intent to describe mental imagery, and in the visual mode, is clear. He described the reported experience as a "visualization." A visualization can indicate a graphic representation, i.e. a physical embodiment of an idea or mental image. But Hadamard seems to suggest that his visualization was purely a mental event. Hadamard's description of the image supports his assessment of the reported perception as a (mental) visualization: "a square of whose sides only the verticals are drawn and inside of it, four points being the vertices of a rectangle and joined by (barely discernible) diagonals." Hadamard's reference to the image as a diagram is entirely consistent with my definition of diagrammatic imagery. In fact, Hadamard's is an exemplary model because the image is only related to the illustration of an idealized geometry. His additional reference to the diagram as "schematic" adds further emphasis to the linear, blueprint quality of the imagery, and perhaps to the visual modality as well. Hadamard's description of the reported perception as a mental image suggests that his opening statement, "I see," was apparently a metaphor for the perception of mental imagery and not the effect of light on the eyes.

Hadamard also remarked that the reported imagery involved a discovery, although this point, as well as the circumstances surrounding this incident were more fully elaborated in a second statement made by Hadamard in reference to the same event.

> One phenomenon is certain I can vouch for its absolute certainty: the sudden and immediate appearance of a solution at the very moment of a sudden awakening. On being very abruptly awakened by an external noise, a solution long searched for appeared to me at once without the slightest instant of reflection on my part--the fact was remarkable enough to have struck me unforgettably--and in a quite different direction from any of those which I had previously tried to follow (Hadamard, 1945, p. 8; see Rugg, 1963, p. 8; Koestler, 1964, pp. 116-7; cf. Shepard, 1978, p. 140).

In this statement Hadamard insists that the solution was discovered at the moment of awakening, but he did not mention the mental imagery described in the earlier statement. His description that the imagery "appeared" could be a metaphor to indicate a moment of realization or discovery, potentially non-imagistic, but this reading is inconsistent with his report in the earlier statement. Hadamard's statement that the solution appeared could indicate the perception of mental imagery, because in the earlier statement he had reported specifically that the discovery was visualized. The implication between the two statements is that mental imagery was involved in the moment of discovery (illumination).

Hadamard's report that the image/solution appeared at the moment of awakening suggests that it could be related to a hypnopompic experience; or possibly it was the period of sleep that provided an important function, such as relaxation or dreaming, that helped to clear his mind of more mundane matters. His report that the solution occurred "without the slightest instant of reflection on my part," suggests that the realization of the solution, as well as the perception of imagery were entirely spontaneous and unintentional. He did not report to have manipulated the imagery in any way, nor did he report to have had any other experiences involving imagery of this sort. Hadamard's report that the solution appeared "without reflection," and "suddenly on being very abruptly awakened" suggests that it may have been the distance from the problem provided by sleep that facilitated his recognition, or in this case perhaps it is appropriate to say his visualization of the elements already at his disposal.

4.3.8 Nikola Tesla

Soon after emigrating to the United Stated from Croatia, Nikola Tesla began work as an assistant in Thomas Edison's laboratory, but soon left to pursue his independent interests. Ironically, it was only four years later, when Tesla was 31, that he invented the polyphase alternating current power system, or AC generator, rapidly making Edison's own direct current system obsolete (Tesla, 1919, p. 7). He also invented fluorescent lighting, as well as dozens of other electrical devices (Tesla, 1919; Shepard, 1978, p. 142). Tesla was awarded, posthumously, with the patent for wireless transmission that made radio possible (West, 1991, p. 142; see Tesla, 1919, p. 8).

Tesla wrote that one evening, while he was walking in a park at sunset with a friend and reciting poetry, he invented the design for the AC generator during an experience reportedly involving mental imagery.

> (The) idea came like a flash of lightning and in an instant the truth was revealed. I drew with a stick in the sand the diagrams shown six years later in my address before the American Institute of Electrical Engineers, and my companion understood them perfectly. The images I saw were wonderfully sharp and clear and had the solidity of metal and stone, so much so that I told him: "See my motor here, watch me reverse it." I cannot begin to describe my emotions. . . For

a while I gave myself up entirely to the intense enjoyment of picturing machines and devising new forms. It was a mental state of happiness about as complete as I have ever known in my life. Ideas came in an uninterrupted stream and the only difficulty I had was to hold them fast. The pieces of apparatus I conceived were to me absolutely real in every detail, even to the most minute marks and signs of wear. I delighted in imagining the motors constantly running, for in this way they presented to the mind's eye a more fascinating sight (Tesla, 1956, p. 198; from Harman & Rheingold, 1984, p. 58; cf. Shepard, 1978, p. 142; see Hunt & Draper, 1964, p. 34).

Tesla was taking an evening walk in the outdoors when this experience reportedly occurred. Exercise, repetitive movement, the change of scenery, the evening sky, even the fresh air could all have contributed to his "flash" of insight. Furthermore, Tesla was with a companion, and reciting poetry at the time; both factors could have stimulated his cognitive processes.

Tesla's description that the idea "came in a flash of lightning" suggests that the idea was entirely spontaneous; however, he did not specify that it was a mental image. Later on in the report Tesla stated that, "Ideas came in an uninterrupted stream;" those ideas are not specifically identified as images either. He described the reported imagery specifically after the idea(s) had already occurred to him, and after he reported to have drawn the diagrams in the sand. He wrote that the diagram was so complete that his companion apparently "understood them perfectly," and that they were the same diagrams presented six years later at a formal presentation. But there is no statement that those diagrams drawn in the sand were first perceived as mental images. Rather, Tesla's reported mental imagery seems to have been facilitated by those drawings; but, perhaps the reported imagery was also a direct response to the ideas themselves, which presumably were non-imagistic.

Tesla's report that he "saw" the images is a little misleading because it would have been impossible for him to have seen those images with his eyes: they were reportedly being invented for the first time at that moment. Furthermore, the images he proceeded to describe seem to involve far more than could be expressed by diagrams drawn in the sand with a stick. Apparently he was using "to see" in a metaphoric sense, to indicate the perception of mental imagery. His reference to seeing does suggest however that his reported perceptions were in the visual mode.

Tesla's description that the images "were wonderfully sharp and clear and had the solidity of metal and stone" suggests a remarkable degree of vividness, and possibly an almost hallucinatory quality. Although he seemed to have recognized the perceptions as mental images, Tesla reported to have said to his companion, "See my motor here, watch me reverse it." Was Tesla referring to his diagram in the sand, or was the mental image he perceived so vivid that he expected his friend to see it? His later statement that "the pieces of apparatus I conceived were to me absolutely real" seems to suggest not that he believed the imagery existed beyond himself, but that the image accurately represented the operation of the motor, reportedly "even to the most minute marks and signs of wear." His report suggests specifically that he verified his invention (idea) through his observation of mental imagery.

The imagery Tesla reported to experience was accompanied by a blissful state, almost to the degree of a religious rapture, "It was a mental state of happiness about as complete as I have ever known in my life." This state could have resulted from his realization of the significance of his invention, certainly it was that important. But, his description suggests that his satisfaction was largely in the act of experiencing the reported imagery itself. He wrote, "I gave myself up entirely to the intense enjoyment of picturing machines and devising new forms." This suggests that although the initial idea had reportedly struck him like a flash of lightning while he was otherwise pre-occupied, the act of sustaining the mental imagery required his complete and undivided attention. There is also a sense that he was relinquishing normal control in some way, like Kekule (see above), and perhaps his willingness to give himself up to that experience facilitated the "uninterrupted stream" of ideas.

Tesla's account suggests that the original idea occurred spontaneously, but that the reported imagery was created intentionally as a way to devise applications for possibly non-imagistic ideas. Furthermore, the reported mental imagery was involved in both the development of his idea as well as in the final design. Several factors could have contributed to Tesla's reported imagery, but according to his own account he had developed remarkable skills involving mental imagery beginning at an early age.

> In my boyhood I suffered from a peculiar affliction due to the appearance of images, often accompanied by strong flashes of light, which marred the sight of real objects and interfered with my thought and action. They were pictures of things and scenes which I had really seen, never of those I imagined. When a word was spoken to me the image of the object it designated would present itself vividly to my vision and sometimes I was quite unable to distinguish whether what I saw was tangible or not. This caused me great discomfort and anxiety. . . . They seem to be unique although I was probably predisposed as I know that my brother experienced a similar trouble. The theory that I have formulated is that the images were the result of a reflex action from the brain on the retina under great excitation. They certainly were not hallucinations such as are produced in diseased and anguished minds, for in other respects I was normal and composed. To give an idea of my distress, suppose that I had witnessed a funeral or some such nerve-racking spectacle. Then, inevitably, in the stillness of the night, a vivid picture of the scene would thrust itself *before* my eyes and persist despite all my efforts to banish it. Sometimes it would remain fixed in space though I pushed my hand through it.
>
> To free myself of these tormenting appearances, I tried to concentrate my mind on something else I had seen, and in this way I would often obtain temporary relief; but in order to get it I had to conjure continuously new images. It was not long

before I found that I had exhausted all of those at my command; my "reel" had run out, as it were, because I had seen little of the world--only objects in my home and the immediate surroundings. As I performed these mental operations for the second or third time, in order to chase the appearances from my vision, the remedy gradually lost all its force. Then I instinctively commenced to make new excursions beyond the limits of the small world of which I had knowledge, and I saw new scenes. These were at first very blurred and indistinct, and would flit away when I tried to concentrate my attention upon them, but by and by I succeeded in fixing them; they gained in strength and distinctness and finally assumed the concreteness of real things. I soon discovered that my best comfort was attained if I simply went on in my vision farther and farther, getting new impressions all the time, and so I began to travel--of course, in my mind. Every night (and sometimes during the day), when alone, I would start on my journeys--see new places, cities and countries--live there, meet people and make friendships and acquaintances and, however unbelievable, it is a fact that they were just as dear to me as those in actual life and not a bit less intense in their manifestations.

This I did constantly until I was about seventeen when my thoughts turned seriously to invention. Then I observed to my delight that I could visualize with the greatest facility. I needed no models, drawings or experiments. I could picture them all as real in my mind. Thus I have been led unconsciously to evolve what I consider a new method of materializing inventive concepts and ideas, which is radically opposite to the purely experimental and is in my opinion ever so much more expeditious and efficient (Tesla, 1919, pp. 31-32; see Hunt & Draper, 1964, p. 184; Harman & Rheingold, 1984, p. 55 ff.).

Tesla reported that he intentionally developed mental imagery skills beginning at an early age in response to what he described as a "peculiar affliction." Tesla suggests that the affliction, that resulted in the symptomatic "appearance of images," was possibly genetically carried because he reported that his brother suffered from similarly traumatic experiences as well. Tesla described the images as "pictures of things and scenes I had really seen, never of those I imagined." The pictures Tesla described are pictorial mental images. His statement that they were "never imagined" scenes indicates they were representations of real events, and not purely based on fantasy.

Interestingly, Tesla also reported imagery in response to spoken words, "the image of the object it designated would present itself vividly to my vision," suggesting a synaesthesia experience where auditory signals stimulated visual perceptions. Tesla's statement that the reported imagery presented itself to his <u>vision,</u> is again a little misleading because he seems to be referring to strictly mental phenomena, but it does again suggests the visual modality of the imagery.

Tesla's report that "sometimes I was quite unable to distinguish whether what I saw was tangible or not," suggests that there was a hallucinatory quality. Tesla objected to this interpretation, writing that: "They certainly were not hallucinations such as are produced in diseased and anguished minds." Tesla may not have been diseased or anguished; certainly he was a distinguished inventor. But he did report confusion over whether the images were tangible or not, causing "great discomfort and anxiety;" and the images were "often accompanied by strong flashes of light, which marred the sight of real objects and interfered with my thought and action;" he even described them as "tormenting." The images may not have been the type of hallucination that Tesla seemed to protest, but there were hallucinatory features nonetheless.

Tesla reported that he developed an ability "to conjure" images, as he described it, in response to the sudden appearance of undesired images. He reported that by concentrating on images of his own selection he "would often obtain temporary relief." He reported that the tormenting images were so persistent that he soon exhausted his "reel" of stored images, and "instinctively commenced," perhaps out of desperation, to reportedly create new images, of places he had never seen and people he had never met. Tesla's description of them as "not a bit less intense in their manifestations" than real people and places again suggest a hallucinatory quality.

As a result of his reported practice of using select imagery as a means to fend off other, undesirable images, Tesla reported that he had developed an ability to "visualize with the greatest facility. This statement suggests that the imagery he reported in conjunction with the invention of the AC generator was not an unusual experience for him, and possibly was the result of a disciplined process of invention. Tesla may have been self taught in this regard, however, his description of this method as "new" is largely overstated in light of statements provided but other scientists and inventors, many of who are represented in this study. His hubris was probably more of a reflection of the self taught nature of his reported abilities than of their originality as a scientific method.

Tesla described creating mental images as a "method of materializing new concepts and ideas." Of course mental images are not material, and his statement presumably refers to the process of creation, as opposed to production; however his use of this term may be the result of the vividness with which he reported to perceive them. More importantly, the concepts and ideas were not specifically described as images. The method of materializing may refer to the reported ability to observe (perceive) mental images as if they were real. The images were a medium for Tesla to translate his ideas (theoretically) into operational inventions. Tesla maintains this distinction throughout his reports.

Tesla wrote about his method of inventing that:

> 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 a single exception (Tesla, 1919, p. 33).

Some of Tesla's self-proclaimed abilities are rather fantastic, and in fact some writers have implied exaggeration on his part (Shepard, 1978, p. 142); but reports from other inventors not nearly as distinguished as Tesla (see Rossman, 1931; and Platt & Baker, 1931; cited under secondary data below) suggest his reported abilities are more common among inventors than might be expected. Again, Tesla seems to differentiate between ideas and images, suggesting that the images were mental constructs or applications of the ideas. This report is different from the previous statements because in it Tesla suggests that "imagination," i.e. mental imagery was not simply a way to test (verify) inventions, but also his primary method for developing ideas (saturation).

Tesla reportedly developed, completed, and verified his inventions through a process intentionally involving the use of mental images. With the AC generator this process reportedly occurred very rapidly, so that within the span of an evening walk the design was completed.

4.3.9 Albert Einstein, part 1

Einstein was only twenty-one years old and working in a Swiss patent office when, as he later reported, the theory of relativity first occurred to him.

> At that point there came to me the happiest thought of my life, in the following form: Just as is the case with the electric field produced by magneto electric induction, the gravitational field has similarly only a relative existence. *For if one considers an observer in free fall, e.g. from the roof of a*

house, there exists for him during his fall no gravitational field--at least in his immediate vicinity [Einstein's italics]. For if the observer releases any objects they will remain relative to him in a state of rest, or in a state of uniform motion, independent of their particular chemical and physical nature. (In this consideration one must naturally neglect air resistance.) The observer therefore is justified to consider his state as one of "rest" (Holton, 1978a; from French, 1979, p. 156; see Holton, 1978b; and Pais, 1982, p. 178; Rothenberg, 1979, p. 112 ff.; cf. Brown, 1991, p. 17 ff.).

It is interesting to note that both Einstein and Tesla described similar feelings of elation in association with their reported mental imagery experiences. There is a possibility that the state of happiness and well being is not simply the result of the recognition of their achievement, but that in some way it is the cause of the discovery, providing the necessary intrinsic motivation that enabled them to reach the solution. Teresa Amabile has written,

> People will be the most creative when they feel motivated primarily by the interest, enjoyment, satisfaction, and challenge of the work itself--not by external pressures (Hennessey & Amabile, 1988, p. 11).

What Einstein described as "the happiest thought of my life" turned out to be the theory of relativity, which is expressed here in terms of gravitational relativity: "the gravitational field has only a relative existence." In this account Einstein did not refer to the initial "thought" specifically as a mental image; however, there are imagistic elements in the subsequent elaboration. It is unclear from this account whether or not he considered that imagery to be part of the initial thought, which seems to represent the moment of illumination. Mental imagery is specifically indicated by "the observer falling from the roof of a house," and by the movement of "released objects" as perceived by that observer: at "rest" or in "uniform motion."

Einstein's account suggests a possibility that he may have intentionally created the reported imagery subsequent to the thought as a way to demonstrate it, though the report is somewhat ambiguous on this point. Irrespective of the precise moment at which the reported imagery occurred, it does constitute a convincing (mental) demonstration of the theory and may have at least been a way for Einstein to verify his discovery. This account suggests that the reported imagery may have been more closely related to the verification stage than to the moment of illumination, or to the development of the idea. However, Einstein described a significantly different emphasis in another account of the same incident.

> I was sitting in a chair in the patent office at 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 (Pais, 1982, p. 179; see Rothenberg, 1979, p. 112).

In this second account, Einstein described mental imagery more specifically in conjunction with mental imagery. Unlike the earlier statement that is ambiguous on this point, this second report suggests that mental imagery was integral to the discovery. Einstein described both the act of falling and the feeling of weight (gravity). There may have been accompanying perceptions in the visual modality involved, but tactile/kinesthetic imagery (sensations) are indicated more specifically than visual. This second account suggests that it was the perception of the kinesthetic element, the feeling of weightlessness (during free-fall) that caused Einstein to first realize his theory. Unlike the earlier statement where the visual features were emphasized, here he described the kinesthetic modality.

Einstein's references to visual imagery in one account, and kinesthetic in the other are slightly inconsistent, and may suggest that the images were formulated subsequent to the (non-imagistic) discovery, presumably as the need arose, and altered to fit his specific need on each occasion. There is some difference in the content of the images he described in the two different accounts as well. In the first account he uses the example of the motion of objects relative to the observer in free fall; and in the second he refers to the observer's sense of their own weight. Alternatively, perhaps the reported images were less concrete than he described them, possibly occurring across a range of visual and tactile/kinesthetic modalities. Einstein could have been reporting different features of the same imagery experience, suggesting that the original thought perhaps involved more detailed or elaborate observations (perceptions) than he suggested in either of the statements in isolation. Possibly there was some basic visual and/or kinesthetic image involved with the original thought, but the inconsistencies suggest that the reported imagery was less specifically imagistic than Einstein suggests, particularly in the second account, or that they were embellished by subsequent elaboration.

Einstein suggests that the discovery was made not as a result of any specific problems on which he had been working at the time, but as a spontaneous result of his intrinsic (and insatiable) curiosity. There was seemingly nothing unusual about the circumstances surrounding the moment of discovery, except for the occurrence of the discovery itself. He reported that he was sitting in a chair in the patent office where he worked. Presumably he was comfortable because he was off his feet and he was in a familiar environment. The nature of the work cannot have been overly taxing for someone as intelligent as Einstein; it may have stimulated his thinking. But, there is no mention of anything that might have particularly caught his attention or facilitated his discovery. Perhaps, as in a Zen state, it was the routine familiarity itself that precipitated his extraordinary thought.

The reports suggest that this problem had not occurred to Einstein before, and that he had, suddenly and apparently spontaneously solved it in that same moment of recognizing the problem for the first time. This suggests that the reported mental imagery provided the first insight in the creative process. Einstein's theory of gravitation involves more than is contained in these simplistic images, but the imagery does itself provide convincing evidence for the theory (see thought experiments below). Although this experience reportedly represented the first insight for this discovery, it also functioned as the illumination for the discovery, as well as the verification. This seems to be an example where the entire creative process was contained in a single moment.

4.3.10 Albert Einstein, part 2

Mental imagery was reportedly not unfamiliar to Einstein. He described an earlier incident reportedly involving mental imagery that occurred when he was only sixteen years old. Einstein regarded this as his first important scientific observation.

> If I pursue a beam of light with the velocity of light, I should observe such a beam of light as a spatially oscillatory field at rest. However, there seems to be no such thing, whether on the basis of experience or according to Maxwell's equations (Einstein, 1949, p. 53; see Holton, 1972, p. 98; 1978a; French, 1979, p. 156; Brown, 1991, p. 15; cf. Shepard, 1978, p. 135-6).

The example of chasing a beam of light is similar to the example of the observer in free fall in that both rely on observations of hypothetical situations. But the reported imagery here specifically involved the observation of "a spatially oscillatory field at rest." This description seems to indicate an image, but it is somewhat ambiguous and could suggest that either visual or kinesthetic imagery were involved, or both. The imagery in this case is more technically oriented, and not related to the observation of events that are conceivable within the scope of normal experience but to phenomena that are impossible to observe. Although the spatially oscillatory field did not exist on the basis of Maxwell's equations, Einstein theorized its existence on the basis of this reported mental image, or "observation" as he referred to it. If it was the imagery that provided verification for the theory of gravitational relativity, then perhaps his report that this discovery occurred in conjunction with mental imagery also explains his confidence in the findings here. It is interesting to note Einstein's confidence of the results although they were based solely on mental images of unobservable phenomena. In this case, unlike the last, there is no indication of a distinction between thought and imagery. The image of the oscillatory field seems to have represented the moment of illumination itself, and perhaps the verification as well.

In a letter to Jacques Hadamard (1945; see Hadamard above), Einstein tried to describe his thinking process.

> 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 . . .
>
> 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 the second stage, when the mentioned associative play is sufficiently established and can be reproduced at will (Hadamard, 1945, pp. 142-3; see Ghiselin, 1952, p. 43; Koestler, 1964, pp. 171-2; Arieti, 1976, pp. 280-1; Simonton, 1988, pp. 25-6; cf. Wertheimer, 1945; Miller, 1984, pp. 206-7).

Einstein reported that mental imagery was a familiar aspect of his thinking process. This suggests that it may have been "the words or the language" that developed secondarily to the imagery in the discovery of relativity. Einstein's description of "muscular" types of signs/images seems to be consistent with my characterization of the tactile/kinesthetic modality, and there does not seem to be any disagreement with his description of the visual modality either. The word muscular implies the feel of straining muscles whereas the imagery Einstein described relates more closely to kinesthetic sensations, e.g. falling.

In 1905, when he was only twenty-six, Einstein published five separate papers in the *Annalen der Physik*. "Three of them were among the greatest in the history of physics" (Snow, 1979, p. 3; from West, 1991, p. 197). One of these papers, the Special Theory of Relativity, had already been rejected as a doctoral dissertation. C. P. Snow reports that:

> This last paper contains no references and quotes no authority. All of them are written in a style unlike any other theoretical physicist's. They contain very little mathematics. There is a good deal of verbal commentary. The conclusions, the bizarre conclusions, emerge as though he had reached the conclusions by pure thought unaided, without listening to the opinions of others. To a surprisingly large extent, that is precisely what he has done (Snow, 1979, p. 3; from West, 1991, p. 197).

When Einstein was requested to prepare a literature review of this work for a journal two years later, he needed the editor's assistance. "I should note that unfortunately I am not in a position to know everything that has been published on this subject, because the library is closed in my free time" (Pais, 1986, p. 164). Perhaps it was his reportedly imagistic style of thinking that enabled him to circumvent traditional approaches to physics.

4.3.11 John Yellot

John Yellot was working as a research engineer at the University of Chicago when he reported the following experience involving mental imagery.

> I had been working on a scientific problem in which the essential feature was a glass plate subjected to severe

conditions of pressure by heat and steam . . . Plates were expensive, hard to procure, and delay was costly.

I had thought a great deal about the solution of the problem, but with no success. Moreover I had come to the point where the breaking of glass had become a phobia, even causing nightmares. (I remember two in particular in which breaking glass was featured. Everything I heard of a similar sound was immediately feared.) There was a great deal of danger inasmuch as I had to look through the plate at a stream of high pressure steam. My reputation as a scientist was built upon this apparatus; failure seemed imminent.

I had been in New York to deliver a paper on the subject of research. The paper was successful, but other personal matters were disturbing me. I was riding on a crowded bus, much absorbed in these matters so irrelevant to my scientific work, when suddenly the solution of the problem came to me.

In a flash I visualized a drawing of the proper design of the apparatus, immediately drew out a notebook, and, without consciousness of my surroundings, wrote down the answer. I knew it was right. I felt much relieved about this major issue, and told my friends at once about it (from Hutchinson, 1949, p. 22).

Yellot reported that he "visualized a drawing of the proper apparatus." His description that the reported experience was a visualization is indicative of mental imagery, and also suggests the reported imagery occurred in the visual mode. The description of the image as a drawing further indicates the visual modality, and more specifically the type of schematic image defined as a diagram in this study. The report that Yellot subsequently "wrote down the answer" suggests a possibility that he recorded the experience through verbal means because writing is a verbal form of expression. But his description of the reported imagery as a drawing (diagram) suggests that perhaps he intended to use the word "to write" in a more general way to indicate drawing, and not linguistic expression. Nevertheless, his statement implies that a verbal component may have been involved, if not in association with the initial visualization (imagery), then possibly in the way he recorded it.

Yellot reported that the solution came while riding on a crowded bus. He did not say whether he was sitting or standing at the time, but the motion of the bus or the steady hum of the engine could have contributed to a meditative state, as with the first report involving Kekule (see above). However, unlike Kekule, Yellot suggests that he was fully awake at the time, and that the bus was crowded. Presumably a crowd of people would offer greater possibility for distractions than the more barren landscape Kekule had described. But Yellot seemed to be undisturbed by the crowd. He also reported that he had just finished delivering a presentation and that it was successful; perhaps this accomplishment provided some sense of relief.

But the relief he experienced, if any, only served to allow him to redirect his attention to "personal matters (that) were disturbing me." Perhaps the completion of his presentation enabled him to concentrate on those other personal matters that he was thinking about when the imagery reportedly occurred. He reported that he was "much absorbed in these matters," and that they were "irrelevant to my scientific work." His report that these matters were disturbing suggests an affective or emotional quality that adds a dimension of intensity to his concentration.

He wrote specifically that the personal matters occupying his attention were irrelevant to his scientific work. Why then would that unrelated direction of thought create an auspicious occasion for the solution to arise? Perhaps the answer is in the question itself, and it was the divergent direction of his conscious thoughts that helped him to realize the solution. His account suggests that being absorbed in unrelated matters facilitated his sudden and unexpected recognition of the solution he had been struggling with.

It was at that moment, on the crowded bus and much absorbed in personal matters that Yellot reportedly experienced the moment of illumination: "suddenly the solution of the problem came to me." Furthermore, he reported that he instantly "knew (he) was right." The sudden imagery experience reportedly represented the verification as well as the illumination stages. Yellot must have possessed all the information he needed in order to solve the problem well before he got onto that bus because there is no report that the solution was developed in the reported mental imagery. The imagery represented a diagram of the completed design, the final solution, so he must have already prepared all the information he needed. Nevertheless, Yellot was only able to put it all together at a point in time when he was specifically not thinking about the problem. Apparently it took a certain distance from working on the problem, or possibly a new perspective in order to find the solution.

The affective quality (disturbance) caused by personal matters could have helped to precipitate a different point of view. Furthermore, Yellot reported that the dangers involved, as well as the risk to his scientific reputation, resulted in phobias about breaking glass and nightmares. He did not describe the particular details of the reported nightmares, but presumably they entailed mental images, perhaps of braking glass. Yellot clearly felt anxiety as a result of having searched unsuccessfully for this solution. Perhaps the anxiety that developed at not solving the problem as quickly or easily as he had hoped inhibited him from solving the problem directly, in his conscious attempts.

His report that the proper design came to him "in a flash" suggests the discovery was an "all at once" type of experience, not requiring further development or elaboration; and that the reported mental imagery did indeed represent Yellot's moment of illumination. Although the word "flash" was presumably used metaphorically for an instant in time, it also carries imagistic connotations and could imply either a flash of light, or perhaps the sudden perception of mental imagery in the visual mode. In addition to occurring all at once, he reported that he immediately knew that the design he had visualized was correct, even though he had only imagined it. The reported mental imagery may have represented the verification as well as the illumination. Perhaps the reportedly imagistic quality of the discovery contributed to Yellot's confidence in the solution, even though it had only just occurred to him.

The solution was reportedly realized all at once, in a visual mental image, and while his conscious mind was otherwise preoccupied. Perhaps, not thinking about the problem by concentrating on unrelated matters facilitated his realization of the solution.

4.3.12 Omar Snyder

Roger Shepard describes the case of Omar Snyder, a scientist who had worked on the "Manhattan Project" to design the first atomic weapon. During the course of that research, Snyder discovered the solution to a problem that, according to the official government report, "turned out to be one of the most difficult problems encountered" (Smyth, 1945, p. 117; in Shepard, 1978, p. 145). The following account is taken from Shepard's report of a personal conversation with Snyder.

> One day, during lunch hour, Snyder achieved the solution in a manner that was sudden, unexpected, and remains vividly in his memory. He was walking down the hall of one of the laboratories and, in his words, "I had gone one pace past the water cooler when suddenly the entire process for the manufacture of the three metal composite for the fuel elements flashed in my mind instantaneously. I didn't need any drawings; the whole plan was perfectly clear in my head." By the end of the next day he had verified that the entire process did indeed work--just as it had been revealed to him in that brief moment of illumination (Shepard, 1978, p. 145).

Mental imagery is indicated by Snyder's report that, "I didn't need any drawings; the whole plan was perfectly clear in my head."

His statement suggests that the reason he did not need drawings was that he had already perceived those diagrams as mental images, ostensibly in the visual modality. There is no indication that mental imagery was involved in the development of his idea, or that the plan required any further development once it had occurred to him. The reported mental imagery experience carried the completed solution (the illumination), and, like Yellot (see above), seems to have also provided convincing verification of the solution as well, although Ferguson's report does suggest that the functionality of Snyder's invention was objectively tested and verified on the following day. Snyder's statement that the reported imagery "flashed in my mind instantaneously" suggests the illumination, and perhaps the verification were both combined in an all at once experience, again like Yellot's invention.

Nothing unusual is suggested by his report that he was walking down the hallway outside his office at the time the reported imagery occurred. Perhaps the act of walking or the slight change in his surroundings could have distracted his attention away from the work in which he was engaged. The report that it occurred during lunch hour could also suggest he was taking a break from that work, which may have helped to provide a little distance from the problem. His attention to mundane details such as the water cooler and his precise location "one pace past (it)" suggest that his attention was simply directed towards the familiar environment around him when the imagery reportedly was perceived. The reported imagery could have been stimulated by the act of walking, or the change in scenery, however mild, from his workspace to the hallway. Perhaps it was his attention to nothing in particular but simply noticing the mundane details around him facilitated his spontaneous recognition of the solution.

Shepard, who recorded Snyder's report, pointed out that although the solution reportedly occurred to Snyder instantaneously, it involved a series of complex and lengthy processes drawn out over time. This suggests that mental images can condense events that take place over an extended period of time into an instant, adding an interesting dimension to the potential of mental imagery that was also reported by Mozart (see Mozart under secondary data below). Shepard also points out this connection to Mozart's creative process:

> That a process drawn out in time in this way should be pictured, as Snyder emphasized, *instantaneously* . . . reminds one of the famous passage in a letter attributed to Mozart (Shepard, 1978, p. 146; in Ghiselin, 1952, p. 45; see Mozart under secondary data below).

In *The Tao of Physics*, Fritjof Capra wrote, "many Eastern teachers emphasize that thought must take place in time, but that vision can transcend it" (Capra, 1975, p. 186). Capra seems to use the word vision to indicate imagination (mental imagery), and of course imagination not necessarily limited to the visual modality. Time was a crucial element in Einstein's imagery as well, but whereas Snyder and Mozart condensed time into an instant, Einstein's imagery worked in the opposite way to consider an image frozen in time.

4.3.13 James Watson

In his book *The Double Helix*, Watson reported experiences involving mental imagery in conjunction with his discovery of the structure of the DNA molecule. In an earlier chapter, Watson described the unique character of the problem on which he was working, and the strategy he devised (with Francis Crick) to search for the solution.

> The essential trick was to ask which atoms like to sit next to each other. In place of pencil and paper, the main working tools were a set of molecular models superficially resembling the toys of preschool children . . . All we had to do was to construct a set of molecular models and begin to play (Watson, 1968, p. 38).

Watson described using toy-like building blocks to develop a physical model that would satisfy the necessary conditions to accurately represent the DNA structure. Fitting the blocks together in the correct way required the analysis of spatial relationships between the parts. Undoubtedly this process relied heavily on visual skills, like looking at the blocks to determine which would fit together, or "sit next to each other" as Watson wrote. Tactile manipulation must also have been involved in arranging and assembling the blocks. Watson did not report mental imagery at this stage in his creative process, but the use of physical models may have contributed to later experiences by actively involving visual as well as tactile modalities in the problem solving process.

Watson reported that he was laying down after a day of work during a crucial phase in the development of the theory when the following experience reportedly occurred:

> As the clock went past midnight I was becoming more and more pleased. There had been far too many days when Francis and I worried that the DNA structure might turn out to be specifically very dull, suggesting nothing about either its replication or its function in controlling cell biochemistry. But now, to my delight and amazement, the answer was turning out to be profoundly interesting. For over two hours I happily lay awake with pairs of adenine residues whirling in front of my closed eyes (Watson, 1968, p. 118; see Shepard, 1978, pp. 146).

By "pairs of adenine residues" Watson was presumably referring to mental images of their molecular structure, perhaps in a way that was related to the building block models of molecules they were using for their research. The fact that adenine residues were closely related to his research suggests that the reported imagery was related to or possibly stimulated by his involvement in the research. Watson's description suggests that the reported imagery could have been a product of his intense concentration, specifically on the physical models they were building in the lab. The reported mental imagery seems to have been part of a (passive) incubation stage.

Watson reported that it was late ("past midnight") and that he was laying down after working all day; but the report suggests that he was awake at the time the imagery reportedly occurred. If anything, he seemed to have been excited by his efforts. He reported that "to my delight and amazement, the answer was turning out to be profoundly interesting." But Watson had been working on this problem for weeks if not months, and it was very late at the time the mental imagery reportedly occurred. Furthermore he reported that his eyes were closed. He may not have been actually asleep, but his description of the circumstances, and of the reported imagery suggests dream-like elements may have been involved. There is no suggestion that Watson consciously created or directed the reported mental images. His description of adenine residues "whirling" for over two hours suggests that he was simply observing the reported images, and not manipulating them in any way. Perhaps the reported imagery represented a release of nervous tension over having worked on the problem for so long without success; but these elements of his description also suggests that perhaps the reported imagery was in part induced by a hypnagogic state.

Watson's report that the image occurred "in front of my closed eyes" seems to refer to the perception of mental imagery. He may have intended to use the expression as a metaphor to generally indicate the perception of mental imagery; but, there is also the suggestion that the reported imagery was actually perceived to occur at that specific location. Whether Watson believed the eyes were actually involved in some way or not is unknown, but it is interesting to note that the imagery was reported to have occurred specifically at a spatial location in front of his eyes, and not at an abstract point in thought.

The mental imagery reported in the statement above may have contributed to the final discovery, but not in any obvious way, suggesting they were part of a passive incubation process. The actual moment of discovery (illumination) occurred several days later, as he was working on the problem in the laboratory.

> Suddenly I became aware that an adenine-thymine pair held together by two hydrogen bonds was identical in shape to a guanine-cytosine pair held together by at least two hydrogen bonds . . . Conceptually, it was thus very easy to visualize how a single chain could be the template for the synthesis of a chain with the complementary sequence (Watson, 1968, P. 123-25; see Shrady, 1972, p. 72 ff.; Shepard, 1978, pp. 146-7; Rothenberg, 1979, pp. 108-9).

Watson's statement, "Suddenly I became aware," does not in and of itself indicate mental imagery. It simply suggests the spontaneous recognition of a discovery. However, his description of that discovery, specifically that the two pairs would have an identical shape, suggests that the comparison could have been made by means of mental imagery in the visual mode. Watson made no mention of looking at the models at that particular moment when he realized the comparison, indicating an observation of visual mental imagery could have been involved, enabling him to determine the similarity in their shape. Watson may have made the visual comparison relying on mental images and not on physical models. Nevertheless, the use of physical models could have helped him to recognize the shapes of the molecules because those models involved visual, as well as tactile sensory modalities.

In addition to suggesting that mental imagery was involved in the moment of discovery (illumination), Watson's description, again like Yellot and Snyder, suggests that the reported imagery was part of the verification process. His statement that, "it was thus very easy to visualize," suggests that the reported imagery (visualization) provided confirmation (verification) of the solution. Watson's reported use of mental imagery to verify or evaluate ideas may not be isolated to this incident. Watson's reference to this reported visualization as "easy" suggests he may have had other visualization (visual mental imagery) experiences with which to compare this incident. Watson reported that the discovery began suddenly, but there is nothing that would indicate he was specifically surprised by the perception of mental imagery.

Watson reported to have experienced mental imagery specifically on two different occasions during the search for the DNA structure. The first reportedly occurred after midnight while he laying down, and involved over two hours of whirling adenine pairs, possibly related to a hypnagogic state. The reported image of the whirling adenine pairs provided no specific contribution to the solution, but it suggests that imagery was involved at an early stage of the process. The report that those images occurred spontaneously and without intentional direction suggests they were part of the incubation stage. In the second incident, imagery was reported to have occurred in conjunction with the realization of the solution (the moment of illumination); and there are indications that imagery was involved intentionally as a way to verify the results. In both incidents, the reported imagery may have been facilitated by the use of physical models involving both visual and tactile modalities.

4.3.14 Richard Feynman

Richard Feynman invented a method of scientific analysis called Feynman Diagrams that are useful for a range of problems in quantum mechanics. Feynman Diagrams represent the motion of subatomic particles according to directional vectors expressed as lines and arrows on a chart. In an interview, Feynman attempted to define his creative process:

> Feynman: What I am really trying to do is bring birth to clarity, which is really a half-assedly thought-out pictorial semi-vision thing. I would see the jiggle-jiggle or the wiggle of the path. Even now when I talk about the influence functional, I see the coupling and I take this turn--like as if there was this big bag of stuff--and try to collect it away and to push it. It's all visual, It's hard to explain.
>
> Interviewer: In some ways you see the answer--?

Feynman: --the character of the answer, absolutely. An inspired method of picturing, I guess. Ordinarily I try to get the pictures clearer, but in the end the mathematics can take over and be more efficient in communicating the idea of the picture.

In certain particular problems that I have done it was necessary to continue the development of the picture as the method before the mathematics could be really done. I see some kind of vague, shadowy, wiggling lines . . . and perhaps some of the lines have arrows on them--an arrow here or there which disappears when I look too closely . . . I have a terrible confusion between the symbols I use to describe the objects and the objects themselves (from Gleick, 1992, pp. 244-5).

In his typically colorful language, Feynman reported that imagery was an essential feature of his own thought process. Although his report is somewhat vague, the vagueness seems to express the indistinct nature of the experiences themselves, and possibly the inadequacy of the language to translate such reported experiences into words (see literature review above).

The report does not sound very scientific; and Feynman did not describe any specific discoveries or mental imagery experiences in isolation. However, he clearly reported that the perception of mental images was a familiar aspect, if not the defining feature of his creative process. His description of a "pictorial semi-vision" in the first sentence suggests that his creative process began with the perception of mental images that may have been vague but seem to have occurred in the visual mode. The reference to a semi-vision is somewhat ambiguous. It may have been a way to acknowledge the "vague, shadowy" quality of the images "which disappear when I look too closely," as he described them later in the interview, or it could have been used to distinguish his perceptions from the seemingly almost tangible, sometimes hallucinatory mental imagery reported by others (see Tesla above).

Feynman's description that he "would see the jiggle-jiggle or the wiggle of the path" emphasizes the pictorial quality of the mental images; but, presumably it does not suggest that he believed the images were visible to the eye. Although Feynman said in no uncertain terms that his thinking process was "all visual," his description of the motion of the images wiggling, jiggling and coupling suggests that tactile/kinesthetic elements may have been involved. This is also suggested by his description of collecting and pushing "this big bag of stuff." Whatever the big bag of stuff may have been, Watson's description of it suggests there was a tactile/kinesthetic element involved in his perception.

Feynman did not say how frequently these reported images occurred or how long they lasted, but he did describe them as if they were a familiar part of his creative process. He said, "Ordinarily I try to get the pictures clearer," suggesting that imagery was frequently involved, and that it was a way to intentionally (actively) develop ideas: representing the saturation stage. However, he acknowledged that "in the end the mathematics can take over and be more efficient." His comments leave open the possibility that the reported imagery also provided a starting point (first insight) for his investigations, but the testimony is inconclusive on this point.

His report suggests that he could intentionally cause the imagery to occur, "Even now when I talk about (it) I see . . ." However, he also reported that the imagery "disappears when I look too closely." His description suggests that the perception of imagery was easy to evoke, but that those perception were not sustainable under closer examination. Perhaps the reason that he reported to sometimes "continue the development of the pictures before mathematics could really be done" was because the pictures were vague and required clarification before he could communicate them in mathematical terms.

Feynman reported to have perceived imagery spontaneously in conjunction with certain ideas, and then to have intentionally used that imagery as a means to develop the ideas. Mental imagery was reportedly the essential feature of his creative process, specifically during the saturation stage. Feynman Diagrams employ a system of lines and arrows that are closely related to the content in his reported mental imagery; their invention may have been a natural result of his unique (if peculiar) creative process. Feynman's reported imagery provided a method for developing original solutions to scientific problems. Freeman Dyson, a close friend and colleague of Feynman's wrote:

> 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 J. Robert Oppenheimer 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. 55-6).

Feynman's reported perception of mental imagery in conjunction with the development of creative solutions is consistent with Dyson's characterization of Feynman's "mind" (creative process) as pictorial.

4.3.15 Stephen Hawking

Stephen Hawking is a theoretical physicist who holds the position of Lucasian Professor of Mathematics at Cambridge University, a chair once held by Isaac Newton. Hawking's research is on the study of black holes and the origin of the universe, indisputably non-observable phenomena. Hawking is now unable to speak or write due to his affliction with amyotrophic lateral sclerosis (ALS, or Lou Gehrig's disease). As a result he is unable to communicate, except through the use of a computer voice synthesizer designed specifically for him (although he regrets the American accent). In an interview conducted with Hawking for the movie about him 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 (Hawking, 1992a).

"Pictures and diagrams" both are indicative of imagery in the visual modality, and Hawking's report that he could visualize these images "in my head" indicates that they were (reportedly) mental images. Hawking's statement is notable because he reports to have made a conscious choice both to actively use mental imagery as a part of his problem solving process. The report also suggests that he intentionally developed those skills in response to the limitations imposed on him by the disease. Hawking's disease is a physical impediment, but it is <u>not</u> mentally debilitating; his mind is entirely lucid. Mental imagery has reportedly provided him with a cognitive method that enables him to continue research in spite of his handicap. Perhaps his chosen methods have culminated in ideas that Hawking might otherwise not have discovered.

Hawking's reported imagery was intentionally developed to facilitate in his creative process. He suggests that mental imagery is an integral part of his ongoing research. However, there is one incident where Hawking reported that mental imagery was specifically involved in what is probably his most significant discovery.

> One evening shortly after the birth of my daughter I started to think about black holes as I was getting into bed. My disability made this a rather slow process, so I had plenty of time. Suddenly I realized that the area of the event horizon always increases with time. I was so excited with my discovery that I didn't get much sleep that night. The increase

> in the area of the event horizon suggested that a black hole had a quantity called entropy, which measured the amount of disorder it contained; and if it had an entropy, it must have a temperature. However, if you heat up a poker in the fire, it glows red-hot and emits radiation. But a black hole cannot emit radiation, because nothing can escape from a black hole (Hawking, 1992b, p. 92).

Although most scientists at the time believed that "nothing can escape from a black hole," Hawking theorized that some very small particles are emitted from black holes, and it was the realization that reportedly occurred in the account presented here that first suggested this possibility to him. Hawking argued that, like the heated poker, black holes must generate radiation, except that in a black hole almost all of the radiation is swept back into the vortex. The small amount of radiation that does escape has now been verified and is called Hawking Radiation.

The "sudden realization," as he referred to it, that first suggested the possibility of Hawking Radiation to him was that "the area of the event horizon always increases with time." Hawking did not report imagery in conjunction with this realization, but area is a visual-spatial concept, and Hawking used a diagram in his book (Hawking, 1988, p. 86) specifically to represent the area of the event horizon.

Hawking's realization that the area of the event horizon always increases implied that black holes would have a temperature, but a temperature above absolute zero produces radiation in the form of heat. Hawking used the image of the heated poker glowing red hot to demonstrate the emission of radiation If nothing could escape from a black hole then no radiation, in the form of heat or otherwise would be able to escape and there would be no heat loss, no measurable increase in the event horizon; but Hawking's realization predicted some very small particles would escape.

Although Hawking reported the image of the heated poker in conjunction with his discovery, the image may have been part of his explanation of the theory rather than a part of the discovery itself. The image may have been developed subsequent to the discovery (illumination) as a way to clarify and/or to express his idea. The image of heating a poker in the fire seems unrelated to the event horizon of a black hole; however, the image of the poker as glowing red-hot and emitting radiation has a lot to do with the formation of the stars and the cosmos. Perhaps the image of a hot object glowing with radiation emissions had something to do with the illumination of the discovery, but the part about putting a poker in the fire may have been a later elaboration that was developed in order to bring the concept into the realm of everyday human experience. It is an interesting feature of his report that Hawking employed common, everyday type of knowledge to describe the behavior of the most powerful and mysterious objects in the universe. Einstein's theory of relativity was similarly founded on such basic precepts.

In some respects, pictures and diagrams were the logical medium to demonstrate some of the properties that Hawking studies, like event horizons; but there is also a possibility that his unique method, developed out of necessity, itself provided the opportunity for new ideas to arise.

4.4 Secondary data

This secondary group of data did not meet the requirements for inclusion in the primary set. Several are from secondary sources and not the subjects themselves; others are not connected with specific products or results. The results of the secondary data were calculated separately from the primary data, which consisted of exclusively first person accounts of mental imagery involved in scientific problem solving. Although the secondary data may have compromised the integrity of the primary group, nevertheless they represent reported imagery experiences that are worth considering in the context of this study.

4.4.16 Thomas Blanchard

In 1822, Thomas Blanchard invented a lathe that could reproduce identical copies of a gun stock (Porterfield, 1941, p. 103).

> (One day,) while manifold schemes for this machine were afloat just below the conscious level of his thought, he was driving home through Brimfield. . . . In an instant there emerged to his imagination a hinged carriage to hold a feeling wheel, and beside it, a twin cutting and copying wheel. He cried, "I have got it!" (Illes, 1912, p. 113; see Porterfield, 1941, p. 103).

The description of the machine, and the report that it "emerged to his imagination" suggest that imagery was involved, specifically in the visual modality. The description of "manifold schemes afloat just below the conscious level" is somewhat vague, but seems to suggest at least that the machine was in the periphery of his thoughts at the time, and possibly that he was in the incubation process when the reported mental imagery occurred. The report suggests he was vaguely aware of this process, but that it was not the focus of his attention.

The report that the imagery occurred while driving (presumably in a horse drawn carriage), suggests there may have been something about the act of driving that helped to facilitate the imagery. Perhaps (like the bus rides described by Kekule and Yellot), the driving helped to induce a meditative state, allowing thoughts and images to flow more easily; or possibly it occupied a part of his mind that had inhibited him from finding the solution earlier. In either case, the moment of discovery (illumination) seems to have happened all at once ("in an instant"), reportedly as a visual mental image. His exclamation "I have got it," presumably a reference to Archimedes' famous discovery, further suggests that the reported mental imagery may have provided the verification as well as the illumination.

4.4.17 <u>Niels Bohr</u>

While he was still a student of physics, Bohr was asleep one night when he reportedly had a dream in which a model of the atom was revealed. According to Krippner and Hughes:

> (Bohr) saw himself on a sun composed of burning gas. Planets whistled as they passed by him in their revolutions around the sun, to which they were attached by thin filaments. Suddenly the burning gas cooled and solidified; the suns and planets crumbled away. When Bohr awakened he realized that he had conceived the model of an atom. The sun was the fixed center around which electrons revolved. Much of the basic theory that forms the foundation for atomic physics came from Bohr's dream (Krippner & Hughes, 1970, pp. 41-2; see Harman & Rheingold, 1984, p. 36).

The description of planets revolving around a sun "to which they were attached by thin filaments" suggests that Bohr perceived those elements as mental images in the visual mode. Although it was the reported visual imagery that seems to have been the most prominent feature in Bohr's reported dream, there are indications that he may have perceived mental imagery in other modalities as well. The description of "a sun composed of burning gas" does suggest visual imagery on the one hand, but on the other it may also suggest there was a perceived temperature association that would indicate the tactile/kinesthetic mode. The report that the burning gas suddenly "cooled and solidified" may be a further indication that the tactile modality was involved. Perhaps Bohr recognized that the reported image of the sun had cooled only because it had changed visually, possibly darkening or shifting toward cooler colors, like blue. But there is an implication that the imagery may have included a tactile component involving a perceived temperature change. Perhaps the perception of the solidification of the gases was likewise accompanied by a physical (tactile/kinesthetic) association. The description of planets "whistling as they passed by" further suggests that perceptions of mental imagery in the auditory mode may have been involved. It is not completely clear whether the report that he "saw himself" on the sun refers to the perception of a mental image representing his own body, or if it was used to indicate that his point of perception seemed to emanate from a position on the sun. In either case it again underscores the visual quality of the reported mental imagery.

There is no indication that Bohr intentionally manipulated or altered the imagery in any way. It seems clear in this case that the reported imagery was a product of dream processes that unfolded as he has sleeping. Bohr may have been in a particularly deep state of sleep because the report suggests that he did not consciously realize that the image represented a model for the atom until later when he woke up. However, the report that the images stayed with him until he awoke, and that they were remembered in such great detail suggests that he recognized some special significance in this reported dream either while it was happening or very soon thereafter, or it may have been lost. The discovery of his model involved a combination of the reported dream images and conscious reflection on those images in a waking state of mind. Holton, who has written extensively on Einstein (1972; 1978a; 1978b; see Einstein above), wrote:

> Bohr confessed that originally he had not worked out his complex atomic models by classical mechanics; they had come to him "intuitively . . . as pictures," representing events within the atom (from Edwards, 1986, p. 46).

Holton's description of Bohr's discovery having resulted from the perception of "pictures" reiterates and affirms that mental imagery, specifically in the visual modality was central to Bohr's illumination. It also suggests the reported imagery was pictorial, which is consistent with the description of the imagery in the first report by Krippner and Hughes (above). However, Holton made no comment as to other possibility of other modalities involved. The structure of the model was represented by the visual elements in the reported mental image; but there is still a possibility that perceptions in other modalities could have helped this image to stand out and create a more lasting impression. The possible perception of tactile and auditory modalities may have caused him to notice this mental image more closely than others.

Holton's report that the discovery was "not worked out" by traditional means suggests that the saturation stage (the working out process) had not occurred prior to the dream suggests that the reported imagery represented both the saturation and incubation stage. There is an implication that the reported mental imagery may have contained the entire creative process even though this was a single experience with a relatively short duration, limited to the time span of the reported dream. Nevertheless there is no specific confirmation that the first insight or the verification stages were realized in conjunction with mental imagery.

The reported mental image represented the model for the atom (itself an unobservable phenomenon), but the illumination itself was not contained completely within the moment of perceiving the imagery. The reported mental imagery occurred while he was asleep and apparently dreaming: The significance of the imagery was recognized after waking up. There is no report that Bohr had been working on this specific problem before this experience reportedly occurred, suggesting that the reported imagery may have represented his first insight into the problem. But presumably there was some form of saturation and/or incubation that occurred prior to the discovery, suggesting the first insight had also occurred at an earlier point in time. The report certainly suggests that imagery was most closely related to the illumination process, though perhaps representing (not the first insight but) a micro insight or realization related exclusively to the illumination stage. Although imagery is commonly associated with dreaming, this was apparently an isolated incident for Bohr involving an important discovery reportedly revealed through mental images in a dream.

4.4.18 James Watt, part 2

Watt invented a new method for making lead shot during a second incident reportedly involving mental imagery (see Watt under primary data above). This second case reportedly involved a dramatically different set of circumstances from the first incident reported by Watt. Krippner and Hughes report that:

> Watt had been working on lead shot for shotguns. The standard process, a costly one, involved cutting or chopping metal. About this time Watt had a recurring dream. He seemed to be walking through a heavy storm; instead of rain, he was showered with tiny lead pellets. The next morning he interpreted his dream to mean that molten lead, falling through air, would harden into small spheres. Watt melted several pounds of lead and flung it from the bell tower of a church that had a water filled moat at its base. Hastening down the stairs, he scooped tiny lead pellets from the bottom of the moat and revolutionized the lead shot industry (Krippner & Hughes, 1970, p. 42).

Mental imagery is indicated by Watt's reported perception, during a dream, of walking through a storm of "tiny lead pellets." The report that he perceived himself to be walking suggests that kinesthetic sensations were involved, and the shower of pellets suggests that they may have been perceived in a tactile way. Although there may have been a visual component involved in the reported perception of the lead pellets, there is no reference to specifically visual imagery, suggesting the reported imagery may have been perceived primarily in the tactile/kinesthetic mode (walking, and being showered with pellets).

The imagery reportedly occurred during a dream, ostensibly while he was asleep. The description of the dream as "recurring" is somewhat confusing because the report states that Watt realized the discovery "the next morning." Did he make the discovery after the first of these recurring dream images, or on a subsequent occasion?

If several repetitions were required, then what was different about the final incident? Did repeated occurrences prepare him for the final realization, or did the reported imagery change over time, developing until the connection was apparent? The report seems to imply that the dream image had recurred on more than a single occasion before the discovery was made, and that the image did not change or develop significantly with repeated occurrences. Perhaps, like Kekule, Watt's "mind's eye was rendered more acute by repeated visions of this kind."

The reported imagery seems to have been the basis for the invention, but it did not in itself represent the completed invention. The invention required an act of "interpretation" which Watt was reportedly not able to perform until the following morning, after he had waken up, like Bohr (see above). These reports are unlike Mendeleev's report that indicates he awoke at once and wrote it down (see above). There is no indication that either Watt or Bohr recognized the significance of the reported mental image while they were dreaming. Nevertheless, the report that they remembered the dreams at all suggests the significance of the dreams was noticed on some level, enough to create a lasting impression.

Because the invention required Watt's conscious interpretation the following morning, the reported imagery did not represent the completed illumination stage; but it does seem to be most closely related to the illumination. Watt had been working on this problem prior to the reported dream imagery, indicating that he was already into the saturation and perhaps the incubation stage. The reported mental imagery represented an unexpected scenario: lead pellets falling through the air. It was that image that suggested to Watt the solution to the problem. But the idea that perfect spheres could be produced by dropping molten lead from a sufficient height into a body of water to cool and harden the resulting pellets involved more than is suggested by the reported dream alone. The reported mental imagery was most closely related to the illumination stage, but did not represent the completed solution. Again like Bohr (see above), Watt's illumination began while he was asleep, and reportedly dreaming. The illumination culminated with his conscious interpretation the following morning after waking up.

4.4.19 Elias Howe

After years of struggling to invent a sewing machine, Elias Howe reportedly discovered the solution during a dream.

> Elias Howe had been frustrated for many years by his failure to perfect the sewing machine. One night he dreamed he had been captured by savages and dragged before their King. The King issued a royal ultimatum. If Howe did not produce a machine in 24 hours, he would die by the spear. Howe failed to meet the deadline and saw the savages approaching. The spears slowly rose and then started to descend. Howe forgot his fear as he noticed that the spears all had eye-shaped holes in their tips. He awakened and realized that the eye of his sewing machine needle should be near the point, not at the top or in the middle. Rushing to his laboratory, he filed a needle to the proper size, drilled a hole near its tip and inserted it in the machine. It worked well and the problem was solved (Krippner & Hughes, 1970, p. 42; see Shepard, 1978, p. 148; Starker, 1985, pp. 92-3).

The imagery Howe reportedly perceived occurred in the context of a dream while he was asleep. The report that Howe was "captured by savages and dragged before their King" in the dream seems to suggest that imagery in the visual mode was involved. The report that Howe "saw the savages approaching," after failing to meet the King's deadline, also indicates that the imagery was perceived as visual. There is also a possibility that the perception of being dragged could have involved the tactile/kinesthetic mode, but this interpretation is speculative and unsubstantiated by the text. The description of a "royal ultimatum" issued by the King suggests that verbal communications were involved, possibly perceived to have occurred in the auditory mode. The reported imagery in this case involved a narrative story including visual, as well as auditory (verbal) and possibly even tactile/kinesthetic perceptions.

The revelatory aspect of Howe's reported dream was the visual image of the spears with "eye-shaped holes near their tips." According to the report, Howe was being threatened by the spears in the dream, but, he "forgot his fear" upon noticing those holes. There is no explicit description as to why he forgot his fear, but the implication is that even during the dream he was cognizant of the connection between the uniquely shaped spears and the needle that completed the design for the sewing machine. The suggestion that he was in some way conscious of the significance of the image even while he was asleep is supported by the implication that he did not continue to sleep, but (like Mendeleev, see above) woke up immediately subsequent to the revelation, and "realized that the eye of his sewing machine needle should be near the point, not at the top or in the middle."

The report that all he needed to do in order to verify his invention was to drill a hole near the tip of a sewing needle and insert it into the machine suggests that the construction of the machine itself was entirely complete, with the exception of the needle, before the mental image reportedly occurred. While the image of the spear seems to have been a crucial element in the solution, the invention was in large part completed independent of and prior to the reported imagery experience. Like Watt and Bohr, there was a conceptual leap from the reported imagery to the final solution. Although Howe seemed to have recognized the significance of the imagery while he was still sleeping and woke himself up to test it, the imagery still did not encompass the entire illumination stage, but again to have provided a micro insight, related not to the <u>first</u> insight but to the illumination, which Howe seemed to have realized immediately.

It is an interesting feature of Howe's reported imagery that the solution to the very problem on which he had been working was perceived in the dream to bear down on him in a somewhat threatening or menacing way; although it reportedly carried the insight for which he sought. Watt's perception of being showered by lead pellets may have been related in a similar way to Howe's experience. This factor could have facilitated their recognition in each case respectively. Affective, or emotional qualities associated with dream imagery is certainly not uncommon, but this special case associated with mechanical invention recalls Evans' statement that his reported imagery (that occurred in bed although he was not sleeping) was accompanied by feelings of "much mental anxiety" (see Evans above).

4.4.20 Michael Faraday

Several writers have reported that Faraday's process of discovery involved mental imagery. Koestler wrote that:

> Faraday was a "visionary" not in the metaphorical but in the literal sense. He saw the stresses surrounding magnets and electric currents as curves in space, for which he coined the name "lines of force," and which, in his imagination, were as real as if they consisted of solid matter. He visualized the universe patterned by these lines--or rather by narrow tubes through which all forms of "ray-vibrations" or energy-radiations are propagated. The vision of curved tubes which "rose up before him like things" proved of almost incredible fertility: it gave birth to the dynamo and the electric motor; it led Faraday to discard the ether, and to postulate that light was electromagnetic radiation (Koestler, 1964, p. 170; cf. Goldberg, 1983, p. 76-77).

The description of Faraday's reported imagery suggests it was exclusively visual, and especially vivid because Faraday himself reported that the images "rose up before him like things." Furthermore, the reported perception of mental imagery seems to have been familiar to him. Although there is no indication of the way this reported ability developed, Koestler's statement implies that Faraday was able to call on it at will. The real world phenomena represented by Faraday's reported images are impossible to see, and yet they exist. The correspondence between the reported mental images and the physical properties they represent suggests the possibility that he may have actually perceived forces that are beyond ordinary human perception. This interpretation is also suggested by West:

> Among his many achievements, his greatest was that he originated the concept of subtle electromagnetic "lines of force," as well as the associated concept of the invisible electromagnetic "field." (These are the same lines as those produced by the effect of a strong magnet on iron filings spread on a piece of paper.) So sensitive was Faraday to these "lines of force" that for him they were as real as matter (West, 1991, p. 29).

West suggests that the reported perception of "lines of force" may have resulted from a "sensitivity" to real phenomena, and not solely a product of the imagination but his position is open to debate. Nevertheless, Faraday's reported mental imagery experiences provided him with unique insight to the function of certain natural forces. The reported mental images seem to have represented his creative method as well as his most significant discovery, seemingly combining all the stages in his creative process.

Throughout each report there is reference to mental imagery in the visual modality. The scientist James Clerk Maxwell, himself represented by a case included in this study (see below), was a friend and a colleague of Faraday's. Maxwell wrote:

> Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centers of force attracting at a distance: Faraday saw a medium where they saw nothing but distance (Maxwell, 1891, pp. ix-x; West, 1991, p. 31).

Maxwell states that the perception occurred "in (Faraday's) mind's eye," clearly indicating that the content was imagistic. It is unclear whether Faraday's ideas originated as mental images, or vice versa, but the two seem to be so closely related that they are impossible to unravel. Faraday seems to have used mental imagery to visualize real phenomena that he was unable to see with his eyes. In his *History of Physics*, Isaac Asimov describes Faraday as,

> Perhaps the greatest electrical innovator of all, he was completely innocent of mathematics, and developed his notion of lines of force in a remarkably unsophisticated way, picturing them almost like rubber bands (from West, 1991, p. 29).

Koestler affirmed the fact that Faraday, although highly talented, was not a traditional type of scientist.

> Faraday lacked any mathematical education or gift beyond the merest elements of arithmetic. Yet the invisible "lines of force," which he visualized as narrow tubes curving in the space around magnets and electric currents and, indeed, pervading the universe, "rose up before him like things" (Koestler, 1964, p. 170; Tyndall 1868; in Shepard, 1978, p. 137).

These descriptions of Faraday's process are reminiscent of Bohr's (see above), who admitted that he had developed his model of the atom without recourse to classical mechanics. In a memorial lecture to Faraday, Helmholtz said,

> It is in the highest degree astonishing to what a large number of general theorems, the methodological reduction of which requires the highest powers of mathematical analysis, he found by a kind of intuition, with the security of instinct, without the help of a single mathematical formula (Kendall, 1955; from Shepard, 1978, p. 137; see Koestler, 1964, p. 170).

Apparently, the intuition to which Helmholtz referred seems to have been a form of visual mental imagery.

4.5 Thought Experiments

A thought experiment is a scientific experiment conducted mentally (Miller, 1984, p. 76 ff.; Brown, 1991, p. 45). The scientist Ernst Mach coined this form of discovery a *Gedankenexperiment* (Sorensen, 1992, p. 51). The remarkable feature is that, in select instances, this type of thinking, sometimes involving imagery, has produced scientifically verifiable results. Galileo was probably the first person to conduct such a feat (Bronowski, 1977, pp. 26-7; see Galileo below). Brown wrote,

> The burden of any constructive thought experiment consists in establishing in the imagination the thought experimental phenomenon. This phenomenon then acts as fairly conclusive evidence for some theory (Brown, 1991, p. 45).

The thought experiments cited below involve the consideration of mental imagery. The first incident involving Einstein (cited under primary data above) constitutes a thought experiment. But, although Einstein reported the incident to have happened in an entirely spontaneous way, certainly it is background knowledge that creates the appropriate conditions. John Norton wrote that:

> Thought experiments in physics provide or purport to provide us information about the physical world. Since they are *thought* experiments rather than *physical* experiments, this information does not come from the reporting of new empirical data. Thus there is only one non-controversial source from which this information can come: it is elicited from information we already have by an identifiable argument, although that argument might not be laid out in detail in the statement of the thought experiment. The alternative view is to suppose that thought experiments provide some new and even mysterious route to knowledge of the physical world (in Brown, 1991, p. 47).

Although the route (to creative discovery) may sometimes seem mysterious, Norton's analysis that background knowledge provides the material from which new thoughts are constructed provides a more positive model for the development of creative behaviors.

4.5.21 Galileo Galilei, part 1

Galileo's proof of this theory that is now referred to as Galilean Relativity was described as a thought experiment involving mental imagery.

> Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small animals. Have a large bowl of water with some fish in it, hang up a bottle that empties drop by drop into a vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal.; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though there is no doubt that when the ship is standing still everything must happen this way), have the ship proceed in any direction you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still (Galileo, 1638b, p. 186 ff.; from Brown, 1991, p. 35)

In addition to being a way to express his idea, the mental imagery Galileo described provided a general proof of the theory as well, constituting a thought experiment. There is no report that mental images were specifically involved in Galileo's initial moment of discovery (the illumination); he may simply have used imagery thereafter as a way to demonstrate his idea. Yet, Galileo himself reported to have proven his theory without ever having physically conducted the experiments he described (see Brown, 1991, p. 36). In the *Dialogo*, he included the following conversation:

> So you have not made a hundred tests, or even one? And yet you so freely declare it to be certain?
>
> Without experiment, I am sure that the effect will happen as I tell you, because it must happen that way (Galileo, 1638b, p. 145; from Brown, 1991, p. 2-3).

If Galileo did reach his conclusions from the proof provided by the thought experiment alone, then perhaps it was the reported imagery that convinced him of the results, even independent of objective verification. Though it is not clear that imagery was specifically perceived in conjunction with the moment of discovery, Galileo's certainty may have derived in part from the pictorial nature of his proof. Having observed the experiment through mental imagery may have in itself been sufficient verification for Galileo. His confidence in the results of imaginary experiments was later echoed by Einstein (see Einstein, part 1 above).

4.5.22 Galileo Galilei, part 2

Jacob Bronowski reported that mental imagery was involved in a different but related discovery by Galileo.

> The 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 *Discourse into Two New Sciences*, 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 says 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, 1638a; cf. Arieti, 1976, p. 276; Brown, 1991, pp. 1-2).

In this example, Bronowski's suggests that Galileo's final discovery (illumination) was directly the result of reasoning based on visual mental images. Bronowski emphasizes that Galileo never actually performed the physical experiments. As with Galileo' first example, this reported incident constitutes a thought experiment because the proof of Galileo's theory is contained within the images themselves; once they have been considered (visualized, by means of mental imagery) their validity is apparent, as Galileo so stridently stated: "because it must happen that way." According to Bronowski's interpretation, mental images were the essential feature in Galileo's realization of the discovery (the illumination).

4.5.23 Isaac Newton, part 1

In his *Principia Mathematica*, Isaac Newton described his theory of gravitation with the aid of imagery.

(A) stone that is projected is by the pressure of its own weight forced out of the rectilinear path, which by the initial projection alone it should have pursued, and made to describe a curved line in the air; and through that crooked way is at last brought down to the ground; and the greater the velocity is with which it is projected, the farther it goes before it falls from the earth. We may therefore suppose the velocity to be so increased, that it would describe an arc of 1, 2, 5, 10, 100, 1000 miles before it arrived at the earth, till at last, exceeding the limits of the earth, it should pass into space without touching it (Newton, 1687, p. 551; see Brown, 1991, p. 7; cf. Rugg, 1963, p. 8; Lowes, 1964, p. 433; Bronowski, 1977, p. 30).

Newton, like Galileo, Maxwell, and Poincare, did not record the actual moment of discovery and may have developed the imagery afterwards as a means of demonstration (Arieti, 1976, p. 271; Bronowski, 1977, p. 30). However, the imagery is the essential feature of the theory, as it was with Galileo and Poincare. It is possible that Newton arrived at his idea (illumination) through purely non-imagistic means, but his reliance on visual imagery to express the content of the theory suggests that imagery may have played a part in the development of the theory as well. Newton even included diagrams in his *Principia Mathematica* to present this theory (Newton, 1687, p. 551), suggesting that visual imagery was central to his conception of the theory, and an aid in promoting its understanding. Although Newton's use of imagery suggests a thought experiment, in fact his conclusions depend on more than is contained in his description alone (Bronowski, 1977, p. 30).

Presumably there were processes other than imagery involved in Newton's discoveries; but it seems to have been the imagery that provided the catalyst. There is little substantiation for the myth that Newton's realization was inspired by a specific observation of an apple falling out of a tree, but Bronowski does state that Newton was in his mother's garden at the time of his epiphany (Bronowski, 1977, p. 30). Perhaps the natural surroundings of the garden, or the security represented by his mother's home facilitated imaginative investigations.

4.5.24 Isaac Newton, part 2

After using imagination images to describe the possibility of breaking free from the earth's gravitational pull, Newton again relied on imagery to describe a second theory: that an object projected at the proper velocity *and* angle would continue in orbit around the earth.

> If we now imagine bodies to be projected in lines parallel to the horizon from greater heights, as of 5, 10, 100, 1000, or more miles, or rather as many semidiameters of the earth, those bodies, according to their different velocity, and the different force of gravity in different heights, will describe arcs either concentric with the earth, or variously eccentric, and go on revolving through the heavens in those orbits just as the planets do in their orbits (Newton, 1687, p. 552.; see Brown, 1991, p. 7; cf. Rugg, 1963, p. 8; Lowes, 1964, p. 433; Bronowski, 1977, p. 30).

Like Galileo, Newton described two distinct theories that are closely related. The first is that an object (a stone) projected fast enough would escape the earth's gravitational field, or "pass into space without touching it" as he so eloquently wrote. The second is that an object projected fast enough and at the correct angle to the horizon would continue in orbit around the earth, like the moon.

As with the last theory, specifically pictorial images are intrinsic to the concept Newton proposed. There is no record of imagery involved in the discovery process, but it seems likely to suspect that it may have been involved in some way, if only because these points are illustrated with diagrams in his the *Principia Mathematica*. The imagery may have provided a conceptual basis for the theory, but, just as in Newton's first example, not the nuts and bolts of the completed proof. Bronowski wrote:

> 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).

Newton was able to compare his calculations with observations of the Moon's period and found that his predictions were highly accurate. Mathematical calculations, in addition to the conceptual image of "a thrown ball that falls in the earth's gravity" were both important aspects in the development of his theory. Perhaps the imagery provided Newton with the initial insight to the problem and the calculations provided the verification; however, Newton's unproven insight that a projectile could hypothetically escape the earth's gravitational field was itself an illumination that turned out to be true, but only as recently as this century.

4.5.25 James Clerk Maxwell

Maxwell, who is mentioned in conjunction with Faraday above, was reportedly a visual thinker himself. Beveridge reports that "Maxwell developed the habit of making a mental picture of every problem" (Beveridge, 1961, p. 76; cf. Shepard, 1978, p. 136). In a famous example, called Maxwell's demon, he attempted to explain the loss of energy due to entropy by creating a thought experiment involving mental imagery.

> The demon thought experiment was Maxwell's attempt to make the possible decrease of entropy in his theory not seem so obviously absurd. We are to imagine two gases (one hot and the other cold) in separate chambers brought together; there is a little door between the two containers and a little intelligent being who controls the door. Even though the average

molecule in the hot gas is faster than the average in the cold, there is a distribution of molecules at various speeds in each chamber. The demon lets fast molecules from the cold gas into the hot chamber and slow molecules from the hot gas into the cold chamber.

> The consequence of this is to *increase* the average speed of the molecules in the hot chamber and to *decrease* the average speed in the cold one. Of course, this just means making the hot gas hotter and the cold gas colder, violating the second law of classical thermodynamics (Brown, 1991, p. 37).

The imagery Maxwell described seems to have been the product of intentional thought processes: he created the images in order to illustrate the intrinsic loss, called entropy, that occurs in the exchange of energy. There is no indication that the concept was initially realized in conjunction with any mental image. Brown refers to Maxwell's demon as a thought experiment (1991, p. 36 ff.) only because a proof is contained within the imagery described, and not because the imagery was involved in the development of illumination of the theory. The imagery in the demon experiment may simply have been created as a persuasive way to demonstrate non-imagistic ideas. However, Maxwell reportedly employed a range of imagery techniques in his scientific method, some of which were closely related to Faraday's (see above). According to Shepard,

> At first, Maxwell visualized Faraday's lines of electrostatic force as tubes in which electric flow was represented by the flow of an incompressible fluid such as water. Later he devised a more elaborate mechanical model to account for magnetic attraction and electromagnetic induction as well as the electrostatic effects explained by the earlier hydrodynamic model. He now envisioned the lines of magnetic force as parallel rotating cylinders separated by ball bearings rotating in the opposite direction (Shepard, 1978, p. 137).

Tricker, a science historian wrote that imagination was central to both Maxwell and Faraday's problem solving method:

An important characteristic feature in their reasoning, which Faraday and Maxwell shared, was the habit of thinking in terms of physical pictures. Although an accomplished mathematician, Maxwell, as has been remarked by many, relied more on diagrams and geometrical notions than on symbols (Tricker, 1966, p. 97; see West, 1991, p. 32).

West continued to write that, "This factor might also help to explain the general incomprehensibility of their work to their contemporaries, who presumably had less extensive visual-spatial capacities" (West, 1991, p. 32). Compare this statement with Dyson's remark about Feynman (above). For both Maxwell and Faraday (as well as Feynman), mental imagery seems to have been a natural or self taught form of problem solving that was integral to their scientific method.

4.5.26 Henri Poincare

Poincare was a mathematician who was also devoted to studying the process of mathematical discovery (Poincare, 1902; 1913; see literature review above). Poincare described the curved geometry of space through an exercise in mental imagery:

> Let us imagine ourselves in a world only peopled with beings of no thickness, and suppose these "infinitely flat" animals are all in one and the same plane, from which they cannot emerge. Let us further admit that this world is sufficiently distant from other worlds to be withdrawn from their influence, and while we are making these hypotheses it will not cost us much to endow these beings with reasoning power, and to believe them capable of making a geometry. In that case they will certainly attribute to space only two dimensions. But now suppose that these imaginary animals, while remaining without thickness, have the form of a spherical, and not of a plane figure, and are all on the same sphere, from which they cannot escape. What kind of geometry will they construct? In the first place, it is clear that they will attribute to space only two dimensions. The straight line to them will be the shortest distance from one point on the

sphere to another--that is to say, an arc of a great circle. In a word, their geometry will be spherical geometry (from Brown, 1991, p. 11-2; Poincare, 1902, p. 37 ff.; cf. Abbott, 1952).

As with Galileo and Maxwell, the images constitute a thought experiment because they demonstrate (prove) his hypothesis; but there is no evidence to suggest that Poincare experienced mental imagery in conjunction with his own illuminating experience. His proof describes visual imagery, but there is a possibility that the images may simply have been used as a demonstration model, like Maxwell's Demon, to illustrate (non-imagistic) concepts. However, the perception of geometric forms (shapes) and spatial relationships (distances) are the essential feature of Poincare's conception; it seems likely to suspect that mental images may have played some part in his initial realization (of the illumination), though perhaps consisting of nothing more than simple lines and shapes. Visual images express the significance of Poincare's concept in a far more obvious way than through purely arithmetic means, which are especially cumbersome with respect to non-Euclidean geometry.

Beginning in childhood, Poincare reportedly developed unique cognitive abilities. Like Tesla and Hawking (see primary data above), these skills were developed largely in response to his own physical limitations.

> At the age of five Henri suffered a bad setback from diphtheria which left him for nine months with a paralyzed larynx. This misfortune made him for long delicate and timid, but it also turned him back on his own resources as he was forced to shun the rougher games of children his own age. His principle diversion was reading, where his unusual talents first showed up. A book once read--at incredible speed--became a permanent possession, and he could always state the page and line where a particular thing occurred. He retained this powerful memory all his life. This rare faculty might be called visual or spatial memory. In temporal memory--the ability to recall with uncanny precision a sequence of events long passed--he was also unusually strong. His poor eyesight

perhaps contributed to a third peculiarity of his memory. The majority of mathematicians appear to remember theorems and formulas mostly by eye; with Poincare it was almost wholly by ear. Unable to see the board distinctly when he became a student of advanced mathematics, he sat back and listened, following and remembering perfectly without taking notes--an easy feat for him, but one incomprehensible to most mathematicians. Yet he must have had a vivid memory for the "inner eye" as well, for much of his work was of the kind that goes with space-intuition and acute visualization (Bell, 1937, pp. 532-33; in West, 1991, p. 135).

Bell's report that Poincare's work (research) involved "space-intuition and acute visualization" supports my suggestion that mental images may have contributed to his creative process during the developmental stages in the experiment cited above. The description of Poincare's reportedly "vivid memory for the inner eye" further indicates that mental imagery was a characteristic ability of Poincare's, and may also indicate mental images were involved in his creative process. The report that he remembered theorems "by ear" could be related to the report that he had memorized every book he had ever read. His reported ability to state the position and page number for any line of text suggests two possibilities. Either the information was retained in a pictorial way (through mental images) so that by visualizing the printed page on which the line occurred he could read off the corresponding page number; or, he may have retained the information through primarily verbal means, possibly involving auditory images, although the way that page numbers would be connected with text through auditory images is unclear. Furthermore, the speed with which Poincare reportedly read and instantly memorized entire novels suggests that the information was digested in a visual way; sounding out every syllable would probably have involved exponentially greater amounts time.

Poincare's physical limitations appear to have functioned as an inspiration for his unique imagery abilities. The development of Poincare's abilities in response to his affliction is reminiscent of Tesla (see above). Bell reports that Poincare developed several remarkable abilities to compensate for his condition. It is unclear exactly which abilities are related to mental imagery, and which are not. Although imagery was employed to demonstrate his ideas, there is no report of any specific discoveries to have resulted from experiences involving mental images. Nevertheless, the nature of his flatland experiment based on shapes and distance suggests that imagery may have been involved in its development and not only its demonstration.

4.5.27 Albert Einstein, part 3

Einstein was famous for his thought experiments. In addition to the two reported by Einstein himself (see above), Arieti describes a third incident of Einstein's involving mental imagery. This one constitutes a thought experiments like the first. They each provide a unique contribution to his universal conception of relativity.

> Einstein visualized himself as a passenger who rode on a ray of light and held a mirror in front of him. Since the light and the mirror were traveling at the same velocity and in the same direction and since the mirror was a little ahead, the light could never catch up to the mirror and reflect any image. Thus Einstein could not see himself in the mirror (Arieti, 1976, p. 281; see Starker, 1985, p. 94).

The reported imagery involved visual observations based the consideration of hypothetical situations, similar to Einstein's earlier examples, as well as to Galileo's (see above). Although the conditions involve traveling at the speed of light, there is no indication that kinesthetic sensations were involved. The report focuses on the visual content in the imagery, or rather the lack thereof because it was the absence of his reflection in the mirror that he noticed. There is no clear indication that Einstein had originally conceived of this theory in this way; it may have (again) been a later construction. But Einstein own emphasis on the visual nature of his thinking processes suggest that possibly these reported images were integral to the discovery (illumination) as well as to their expression.

4.5.28 Albert Einstein, part 4

For Einstein, even time was conceived in a visual, or at least a spatial way. Bronowski describes a final example of Einstein's mastery of the thought experiment.

> 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).

Like the previous example, this report involved the observations of a hypothetical situation as a mental imagery. Again the speed of light is involved, but not as a mental image so much as a conceptual element in the experiment. In both cases relatively simple and straightforward observations were required: the observation of a mirror and of a clock. The condition of traveling at the speed of light does not seem to have complicated Einstein's reported observation (of the visual mental imagery) in any significant way, yet it profoundly altered the results. Einstein (like Galileo, Hawking, and even Maxwell and Poincare) was able to describe elegantly simple experiments that carried remarkably far reaching implications.

4.6 Inventors

The following reports include descriptions of mental imagery and its use in the inventing process. The reports often describe familiar methods without connecting them to specific incidents. They did not qualify for the primary data group because the resulting inventions were either not reported or were relatively insignificant. Nevertheless, the following reports emphasize the importance of mental imagery in the process of inventing and they are worth considering here.

Although the first two examples are from different sources, the remainder were documented in Joseph Rossman's book, *The Psychology of the Inventor* (1931). Having worked for many years as the United States Patent Examiner, Rossman compiled a survey of more than seven hundred inventors. Rossman used anecdotal self reports from that survey to describe methods of invention that have proved successful. Rossman wrote:

> A few of the typical replies of the inventors will now be given in order to illustrate concretely the methods which they follow in inventing. These statements embody the wisdom gained through years of experience and the expenditure of vast fortunes. Anyone interested in inventing will obtain by carefully reading these remarks valuable information which has never been published before (Rossman, 1931, pp. 67-8).

Unfortunately, descriptions of the inventions that resulted from the methods described were omitted from Rossman's data.

4.6.29 Walter Chrysler

In a report provided by Ferguson (who also provided the reports of Evans and Nasmyth above), Chrysler described the perception of imagery in association with an invention, albeit a minor one.

> Walter Chrysler, founder of the automobile company, recounted in his autobiography how as an apprentice machinist he had built, without drawings, a model locomotive that existed "within my mind so real, so complete that it seemed to have three dimensions there. . . . My fingers were an intake valve through which my mental reservoir was being filled; and of course, my eyes and ears were helping in the process, but what I learned with my fingers and my eyes together I seem never to forget (from Ferguson, 1992, pp. 49-50; Chrysler & Sparks, 1950, p. 43).

Chrysler's description of the model locomotive as "within my mind so real, so complete that it seemed to have three dimensions there" suggests that the imagery was specifically pictorial (as opposed to diagrammatic), representing space in a photographic way, unlike blueprints that are limited to contour (outline) drawings. Ferguson's report suggests that it was the experience of mental imagery that enabled Chrysler to complete the design for the locomotive in his mind "without drawings," suggesting it functioned as both the saturation and illumination, and possibly the verification as well.

Chrysler's reference to his fingers adds another dimension to his account. There is nothing in his description of the imagery to suggest that tactile elements were involved. However, his description of his fingers as a sensory "intake valve," suggests that tactile impressions may have contributed to the vivid nature of the reported imagery. Chrysler mentions that "ears were helping in the process," but he specifically attributes greater significance to perceptions including both tactile and visual modalities. James Nasmyth, discussed above, expressed ideas closely related to Chrysler's. Nasmyth wrote:

> The eyes and fingers--*the bare fingers*--are the two principal inlets to trustworthy knowledge in all the materials and operations which the engineer has to deal with. . . . Hence, I have no faith in young engineers who are addicted to wearing

> gloves. Gloves, especially kid gloves, are perfect non-conductors of technical knowledge (from Ferguson, 1992, p. 50; Nasmyth, 1883, p. 97).

Not only is Chrysler's emphasis on the tactile modality echoed in Nasmyth's statement, Nasmyth further emphasized this point through his insistence on working with bare hands. Nasmyth may have intended his condemnation of gloves in part as a metaphor for direct experience, but he also clearly recommended it as a working habit.

Ferguson also reports that Peter Cooper Hewitt, the inventor of the mercury vapor lamp, relied on tactile manipulation. According to a report by a scientist named Michael Pupin (and quoted by Ferguson), "Those who knew (Hewitt), watching him at work, felt that a part, at least, of Hewitt's thinking apparatus was in his hands," (from Ferguson, 1992, p. 50). These reports suggest that tactile experiences with the bare hands are an important aspect of mechanical engineering. Perhaps more significantly, they demonstrate the benefit of learning across a range of cognitive and sensory modalities.

4.6.30 Flinders Petrie

Galton reported that Flinders Petrie, an eminent British Egyptologist, reportedly perceived mental imagery in association with performing mathematical calculations.

> Mr. Flinders Petrie, a contributor to *Nature*, informs me that he habitually works out sums by aid of an imaginary sliding rule, which he sets in a desired way and reads off mentally. He does not usually visualize the whole rule, but only that part of it with which he is at the moment concerned (Galton, 1883, p. 66; see Hutchinson, 1949, p. 20; Shepard, 1978, p. 153).

There is no documentation of any specific discoveries resulting from Petrie's reported mental imagery, but, according to Galton, Petrie's "habitual" method for solving mathematical problems, specifically addition, involved mental imagery. The description of an "imaginary slide rule" suggests the reported imagery was perceived in the visual modality. It is not clear whether the reported image was perceived to resemble a real slide rule that Petrie may have actually seen (with his eyes); but the report that he perceived "only that part with which he was concerned" suggests that the imaginary slide rule was not limited to the dimensions of a real one, but rather that it was "infinitely" expandable and divisible. This is also suggested by his reported ability to "set (the slide rule) in a desired way." Perhaps, for that reason, the imagery represented more of a diagrammatic version of an ideal slide rule than a pictorial representation of a slide rule he had seen or used.

This type of imagery involving numerical calculations is related to Galton's number forms category. Other related incidents are cited in Galton (1883, pp. 79 ff.) and in Corliss (1976; 1982, pp. 319-44). Presumably the slide rule followed a linear orientation that was appropriate for addition, and possibly subtraction, but perhaps inadequate for higher order mathematical functions. The description of this reported behavior as "habitual" suggests that the perception of mental imagery in this context was a regular practice of Petrie's. There is no documentation from Petrie himself describing his reported perception of imagery, but there is a statement from him describing his creative process. Hutchinson quotes Petrie as saying:

> I never try to settle a difficult matter off-hand. I first assemble the material, state the problem as definitely as possible, and, if no solution is evident, leave it alone. From time to time I may look over it to refresh my memory, but never to force a solution. After waiting days or years I suddenly feel a wish to go over it again, and then everything runs smoothly and I can write without effort. There is unconscious growth of mind without perceptible effort in the interval (from Hutchinson, 1949, p. 20).

This statement offers some insight into Petrie's process, but there is no reference to mental imagery. In fact the process he described is strikingly different from that reported in conjunction with the imaginary slide rule. Galton described Petrie's method of calculating in a way that suggests the solution was discovered quickly and easily. Petrie's report of his own process suggests he approached difficult problems directly at first, but, "If no solution is evident," he elected to "leave it alone." Perhaps the mathematical calculations he reportedly performed with the aid of an imaginary slide rule were never so difficult as to ever involve this secondary strategy that involved proceeding in an intentionally indirect manner when no solution was immediately apparent.

Petrie suggests that it was his willingness "never to force a solution" enabled him to solve problems "without perceptible effort." He reported the effortlessness of the solution to result from "unconscious growth of mind." His insistence on allowing difficult solutions to develop spontaneously, seemingly without conscious effort suggests that perhaps the reported imagery involving the slide rule was an effortless process as well.

4.6.31 A. Y. Dodge

> When working out a new device mental pictures present themselves to my mind quite rapidly, more rapidly in fact than I can record them on paper. Therefore, the first step seems to be a process of eliminating the imaginary pictures to reduce the group to those most feasible (A. Y. Dodge, in Rossman, 1931, pp. 68-9).

Dodge's account that the reported images "present themselves" suggests they occurred spontaneously, without his intending to perceive them. However, he also described mental imagery as if it were a familiar procedure in his working process. The description suggests that the reported mental images occurred spontaneously and without intentional direction: They occurred "more rapidly" than he could "record them." Perhaps the reported mental imagery was spontaneous, but, after repeated experiences he had learned to anticipate and utilize this spontaneous imagery as a brainstorming element in his inventing process. His comment that the "first step is a process of eliminating imaginary pictures" seems to refer not to the first insight but presumably to the first conscious or intentional step. The report suggests that mental imagery was involved early in the creative process, possibly in conjunction with the first insight or the saturation stage. Dodge's report that his process involved the reduction of images is unique among the examples included in this study.

The description of recording the images "on paper" could indicate that he wrote out verbal directions, but the description of the imagery as pictures suggests that they were perceived in the visual modality, and that he was recording drawings (diagrams) of the "new devices." Although he did use the word "picture" to describe the reported images, it is not entirely clear whether he perceived the imagery more in a pictorial or in a diagrammatic way.

4.6.32 E. Thompson

> The first step is to conceive a need or use, examining the existing art or processes or to imagine (visualize) a desirable something or process which might respond to or create a demand. . . . Then follows the work of the imagination (creative imagination) which involves the ability to picture in one's mind the device or process as if it were already in existence. In this mental picture the invention is embodied, even tested, so to speak. . . . It is scarcely necessary to add that I regard the imaginative faculty as chief in value to the inventor, as it is to the work of the construction engineer, the artist, the architect, the researcher, etc. I have never tried by chance or numerous experiments to reach the goal, and consequently have never begun a piece of work, invention included, in which I could not in my mind follow the whole thing through to an apparently satisfactory conclusion (E. Thompson, in Rossman, 1931, p. 73).

Thompson described the first step as a process that could potentially involve mental imagery, but not necessarily involving mental imagery, which is unlike Dodge's report (above). Thompson described "the ability to picture the device in one's mind" as the second stage in the inventing process. The picturing ability Thompson referred to in his report seems to indicate mental imagery in the visual mode. The use of the word "picture" may suggest the reported mental imagery was perceived as pictorial, and not diagrammatic. Though the statement is not completely clear on this point, the reference to testing machines as mental images may also suggests a pictorial quality.

Thompson's report suggests that mental imagery was involved more frequently in the development of the device (the saturation stage) than with any other stage in the creative process. Thompson did not report any specific instances of illumination to have resulted from his reported perceptions of mental imagery, however he did indicate that his inventing process involved the development of "the whole thing through to an apparently satisfactory conclusion." This statement suggests that the illumination, as well as possibly some degree of verification were also represented in mental images: "In this mental picture the invention is embodied."

For Dodge the perception of imagery seemed to occur spontaneously, but with Thompson there is a suggestion that the images were created deliberately and functioned as the medium for him to create new designs for inventions. There is no indication of any specific causes that may have contributed to Thompson's perception of imagery, but he suggests imagery was a familiar practice that he was able to consciously direct. His comments, especially with respect to mentally "testing" the inventions recalls the reported perceptions of Tesla's (cited above).

4.6.33 F. F. Forshee

> The actual inventing becomes more or less a problem in mental mathematics--the addition and subtraction of materials; energy; motion . . . it is purely a mental picture which may involve hours, days or years to complete, and it may never be completed due to the fact, after the picture develops, that you begin to see the shortcomings in the invention--or it may develop into a thing of beauty that you can see will have an appeal and will actually be of great service. This "mental painting"--as I call it--does not have to be continued until the job is finished. It can be taken up as you have time and worked on until it develops into a complete picture. As you take up the painting of this picture, you naturally go over it from the beginning and survey it, and if you are satisfied with what you have done so far, you go on building until it is complete.
>
> When this mental picture is complete, you then begin putting your idea into practice, either by the construction of a model or a drawing of a real picture. I do not believe that any inventor has ever made a worth while invention without having consciously or unconsciously painted a mental picture of his idea; in the first place--he may have done some certain amount of experimental work along with the painting. This experimental work was only a process of "paint mixing"--trying to obtain a "right color" for his "mental painting." During this experimental or "paint mixing" process, he may have developed a new "color" or idea which is an inspiration for his next work (F. F. Forshee, in Rossman, 1931, pp. 77-8).

Similar to Thompson's report, Forshee describes his own process of inventing as "purely a mental picture," which suggests mental imagery in the visual modality. The description of "paint mixing" is an intriguing metaphor for the manipulation of mental imagery, and seems to reinforce his description of the visual modality.

Unlike several reports presented in this study that indicate inventions developed quite rapidly with the aid of mental imagery, Forshee indicates a range of durations from hours to years to complete, if ever. His admission is reminiscent of the report from Petrie (above) who insisted on never forcing the solution to a problem, but allowing the process to unfold naturally: "There is unconscious growth of mind without perceptible effort in the interval."

Like Thompson, Forshee described mental imagery as the medium with which he developed inventions, representing the saturation stage. He further wrote that "so long as you are satisfied, you go on building until it is complete," suggesting the illumination could also occur in conjunction with mental imagery.

There is no indication that the reported imagery was spontaneous. For Forshee, developing a design through imagery was a familiar practice that involved a process of deliberate experimentation, again like Thompson.

4.6.34 H. A. W. Wood

> I have never put problems into words, but deal with them mentally without being conscious of their being expressed in language--when the solution comes in the form of an invention, appearing as it often does in a variety of forms. I analyze them without reducing them to paper and never sketch them until my final choice has been made. Then, when my thoughts stand out like clearly cut sculptures, I put them on paper, firstly, as a matter of record, and secondly, as a means of describing to my engineers the mechanism I wish constructed for the purpose of putting the invention to work. Formerly I used to sketch out my inventions and clear them up on paper, but I found this to be a slow and cumbersome process and therefore abandoned it.
>
> I am firm in my opinion that invention, if it be true invention, is wholly a subconscious reaction to past experiences culminating in the wish to satisfy a need (H. A. W. Wood, in Rossman, 1931, p. 116).

Wood seems to describe the spontaneous and unintentional perception of mental imagery in conjunction with the inventing process, similar to Dodge's report that "mental images present themselves to my mind." Again the report suggests that the imagery was perceived in the visual modality. Wood's claim that "invention is wholly a subconscious reaction to past experiences," seems to emphasize the spontaneous nature of his reported imagery; but there seem to have been more than just subconscious processes involved in his "final choice" for the design of an invention.

Also like Dodge, Wood employed a process of eliminating mental images "until my final choice has been made." This is a different process from that described by Thompson and Tesla for example, who reported building up a single mental image rather than selecting from multiple alternatives.

Wood's report suggests that mental imagery was a way to both develop his ideas, indicating the saturation stage, as well as a way to realize the completed design, representing the illumination. His report that his problem solving process is exclusively non-verbal echoes Einstein's self-described mental processes (see Einstein under primary data above), and implies that mental imagery may have been the starting point or first insight for his inventing process as well. There is no indication of specific causes for Wood's reported perception of imagery, but (like Dodge, Thompson, and Forshee) imagery seems to have been a familiar practice that he could control at will.

4.6.35 Seymour Cray

Seymour Cray is responsible for the invention of the Cray super computer, still the fastest computer in the world. According to an article in *Science*:

> (Cray) proceeds by building a visual concept of the whole machine in his head. There are no intermediate steps. He

simply conceives it and then draws it" (Metz, 1978, p. 406; cited in Shepard, 1978, p. 141).

The report suggests that Cray consciously constructs mental images as a method for designing machines. The statement that, "There are no intermediate steps" seems to emphasize that the concept was developed all the way to completion through the use of imagery, so that the only thing left was to draw the plans. According to the report, drawing the plans takes place only after the diagrams are already complete as visual images in his mind. This suggests that mental imagery was perceived throughout the creative process. In particular, Cray's conscious direction of the reported mental imagery in order to develop technical designs indicates the saturation stage; and the report that the designs are fully completed as mental images suggests that the illumination was conceived in conjunction with mental imagery as well. There was no mention as to the possible duration of this process, nor to any of the specific inventions said to have resulted from it, but the report does imply that this was not an isolated experience.

4.7 Poets, painters and composers, etc.

As described in greater detail above (see data validation), these incidents stemming from the arts and humanities are not included in the primary data set because their products are culturally subjective in a way that scientific discoveries are not. Nevertheless, these incidents warrant consideration because they help to elucidate the range of functions attributed to mental imagery. Although the results are not objectively verifiable, they satisfy the data selection criteria in most other ways.

4.7.36 Samuel Taylor Coleridge

Coleridge's account of the opium induced dream in which his poem *Kubla Kahn* was created is one of the most famous and vivid descriptions involving the reported use of mental imagery in creative writing. Coleridge himself described the incident, referring to himself in the third person.

> In consequence of a slight indisposition, an anodyne had been prescribed, from the effect of which he fell asleep in his chair at the moment that he was reading the following sentence, or words of the same substance, in *Purchas's Pilgrimage*: "Here the Khan Kubla commanded a palace to be built, and a stately garden thereunto. And thus ten miles of fertile ground were enclosed with a wall." The author continued for about three hours in a profound sleep, at least of the external senses, during which time he has the most vivid confidence that he composed not less than two to three hundred lines; if that indeed can be called composition in which all the images rose up before him as *things*, with a parallel production of the correspondent expressions, without any sensation or consciousness of effort. On awakening he appeared to himself to have a distinct recollection of the whole. He instantly and eagerly wrote down the lines. At this moment he was unfortunately called out by a person on business, detained for over an hour, and on his return to his room found, to his no small surprise and mortification, that though he still retained some vague and dim recollection of the general purport of the vision, with the exception of some eight or ten scattered lines and images, all the rest had passed away (from Ghiselin, 1952, p. 85; see Lowes, 1964, p. 324-5; Koestler, 1964, pp. 166-7; Harman & Rheingold, 1984, pp. 35-6; cf. Hutchinson, 1949, pp. 94-5; Shepard, 1978, p. 149).

Coleridge wrote that it was the ingestion of what he called an "anodyne" that caused him to fall asleep in his chair. We now know this was a reference to opium, a profoundly narcotic drug. Although he reported to have fallen asleep for "about three hours," his subsequent qualification that he was "in a profound sleep, <u>at least of the external senses,</u>" is somewhat ambiguous. It could refer to a normal dream experience, or, it could refer to a narcotically induced state that was not actually sleeping, yet caused him to feel as if his external senses were asleep. Either interpretation underscores the imagistic quality of the experience. Perhaps Coleridge's reported experience was related to a hypnagogic state: Kekule might have described Coleridge's reported experience as a reverie, much like his own (see Kekule above), although Kekule's report did not involve artificially induced intoxication.

The description that "all the images rose up before him as things, with a parallel production of the correspondent expressions," suggests that the reported images were perceived as visual, and that there was a verbal component as well, though the way that the verbal component manifested is not stated. Possibly auditory images were involved, or perhaps visual images of the written words were perceived. Coleridge's report that the poem was realized "without any sensation or consciousness of effort" suggests that the imagery was entirely spontaneous and not intentionally directed. Perhaps it was a sense of disassociation from having realized the poem in an entirely passive way that caused him to use the third person voice in this report, though this is purely speculative. There are no other reports of mental imagery involving Coleridge, but it is interesting to note that, upon being interrupted, most of the dream and consequently the poem had vanished. In most of the reports we have encountered, the information was permanently committed to memory after being perceived only once as a mental image. Perhaps the opium interfered with his memory, or possibly the dreamed poem, reportedly "two to three hundred lines long," was simply too long to remember (except for a person like Poincare, who reportedly could memorize books on the first reading; see above).

Coleridge's poem reportedly involved a type of dream-like imagery; but, as Coleridge himself admitted, and Lowes elaborated (1964), the dream was strongly influenced by the book *Purchas' Pilgrimage*, which Coleridge reported to be reading at exactly the moment when the experience began. These are the lines from *Purchas's Pilgrimage* that Coleridge was reading as he fell asleep:

> In Xanadu did Cublai Can build a stately palace, encompassing sixteen miles of plain ground with a wall, wherein are fertile meadows, pleasant springs, delightful

streams, and all sorts of beasts of chase and game, and in the middle thereof a sumptuous house of pleasure (Purchas, 1625; from Lowes, 1964, p. 326).

Compare the original text Coleridge had been reading to the opening of his poem:

In Xanadu, did Kubla Khan
A stately pleasure-dome decree:
Where Alph, the sacred river, ran
Through caverns measureless to man
        Down to a sunless sea.
So twice five miles of fertile ground
With walls and towers were girdled round:
And there were gardens bright with sinuous rills,
Where blossomed many an incense-bearing tree;
And here were forests ancient in the hills,
Enfolding sunny spots of greenery.
(Lowes, 1964, p. 327).

Certainly Coleridge's poem displays an artistry unrivaled by the earlier prose. However, comparing them side by side it is apparent that the inception of Coleridge's poem is directly related to those lines (cited above) from *Purchas' Pilgrimage*. The similarities are so striking that Coleridge's memory of the lines he had been reading must have influenced the creation of his own poem. The most important feature for the concern here is that Coleridge, in the narcotically induced state, reported to experience mental imagery occurring spontaneously, as in a dream, and that reported imagery carried the completed lines (the illumination) for a new poem.

The lines reportedly needed no alteration but only to be written out on paper to record them permanently; however, an untimely interruption reportedly caused his memory of the imagery to fail, and he was consequently able to remember no more than "some eight or ten scattered lines and images." In this particular case the imagery seems to have been a response to specifically what he had been reading at the moment when the reported experience began. (Be careful what you read. . .)

4.7.37 Joan Didion

Joan Didion wrote: "I have begun each of my novels with no notion of character or plot or even incident, (but instead, certain) pictures in my mind" (from Shepard, 1978, p. 150). There is not a lot of data in this case on which to elaborate, but it is clear from the report that mental imagery, specifically in the visual modality formed the basis for her character developments. Her report to "have begun each of (her) novels" with pictures (visual mental images) indicates images are involved early in her creative process, suggesting they were perceived in conjunction with both the first insight and the saturation stage.

Didion did not state the degree to which the images with which she began to write were intentionally created, but mental imagery was reportedly a familiar practice. Although writers are presumably most adept at verbal means of communication, it is interesting to note that sometimes they also use visual mental imagery as a technique in the writing process (as Coleridge seemed to have done, albeit unintentionally).

4.7.38 Leonardo da Vinci

The case of Leonardo involved no specific products or discoveries resulting from mental imagery, but nevertheless describes a type of imagery experience. Leonardo wrote:

> It is not to be despised, in my opinion, if, after gazing fixedly at the spot on the wall, the coals in the gate, the clouds, the flowing stream, if one remembers some of their aspects; and if you look at them carefully you will discover some quite admirable inventions. Of these the genius of the painter may take full advantage, to compose battles of animals and men, of landscapes or monsters, of devils and other fantastic things

which bring you honor. In these confused things the genius becomes aware of new inventions, but it is necessary to know well (how to draw) all the parts that one ignores, such as the parts of animals and the aspects of landscape, rocks, and vegetation (from Chipp, 1968, p. 428).

Although none of his surviving works seemed to employ this technique in any apparent way, Leonardo was the first artist we know of to have recognized and documented this phenomenon. The experience he described may possibly be related to pareidolia, which is elaborated in the discussion of Kekule under primary data above. The type of imagery described by Leonardo clearly occurred in the visual modality. Leonardo described the process for inducing such imagery as simply "gazing fixedly" in a single direction. During this century related techniques have been associated with several art movements, notably Surrealism (including Max Ernst, see below), Automatism (a subgroup of Surrealism) and Abstract Expressionism.

4.7.39 Max Ernst

Max Ernst was one of the Surrealist artists from this century to employ the pareidolia type imagery described by Leonardo during the High Renaissance. He wrote:

> It started with my recalling an incident of my childhood when the sight of an imitation mahogany panel opposite my bed had induced one of those dreams between sleeping and waking. Happening to be at a seaside inn in wet weather, I was struck by the way the floor, its grain accentuated by a thousand scrubbings, obsessed my nervously excited gaze. I decided to investigate the symbolism of this obsession and, in order to aid my meditative and hallucinatory faculties, I made from the boards a series of drawings by placing on them at random, sheets of paper which I undertook to rub with black lead. In gazing attentively at the drawings thus obtained I was surprised by the sudden intensification of my visionary capacities and by the hallucinatory succession of contradictory images superimposed, one upon the other (from Ernst, 1948,

pp. 7-11; see Ghiselin, 1952, p. 64; Chipp, 1968, p. 429; cf. Simonton, 1988, p. 39).

Unlike Leonardo who made no mention of altered states of consciousness, Ernst stated that the images originated in "dreams between sleeping and waking." The transition state from sleeping to waking is termed hypnopompic (by Myers, see literature review above); however, from his description it seems clear that Ernst was in a state of falling asleep as opposed to waking up, and should be considered a hypnagogic experience. The distinction matters little since both typically involve the perception of dream-like mental imagery.

Ernst reported that the experience was triggered by the memory of a reportedly similar experience from his childhood, but the aspects of the dream that Ernst described as "visionary" and "hallucinatory" refer specifically to the visual effects produced by staring at drawings made from rubbings of the floorboards. He recognized Leonardo's earlier documentation of this phenomenon, specifically citing Leonardo's comment in his own writing (Ernst, 1948).

4.7.40 Wolfgang Amadeus Mozart

In his short yet busy life, Mozart was perhaps the most productive composer ever to have lived. Mozart himself attributed his generous productivity, in part, to his capacity for mental imagery. In a letter to a friend, he wrote:

> When I am, as it were, completely myself, entirely alone and of good cheer--say, traveling in a carriage, or walking after a good meal, or during the night when I cannot sleep; it is on such occasions that my ideas flow best and most abundantly. Whence and how they come, I know not; nor can I force them. Those ideas that please me I retain in memory, and am accustomed, as I have been told, to hum them to myself. If I continue in this way, it soon occurs to me how I may turn this

> or that morsel to account, so as to make a good dish of it, that is to say, agreeably to the rules of counterpoint, to the peculiarities of the various instruments, etc.
>
> All this fires my soul, and, provided I am not disturbed, my subject enlarges itself, becomes methodized and defined, and the whole, though it be long, stands almost complete and finished in my mind so that I can survey it, like a picture or a beautiful statue, at a glance. Nor do I hear in my imagination the parts successively, but I hear them, as it were, all at once. What a delight this is I cannot tell! All this inventing, this producing, takes place in a pleasing lively dream. Still the actual hearing of the *tout ensemble* is after all the best. What has been thus produced I do not easily forget, it rarely differs on paper from what was in my imagination, and this is perhaps the best gift I have my divine Maker to thank for (from Harman & Rheingold, 1984, p. 33; see Hadamard, 1945, p. 16-17; cf. Tyrrell, 1946, p. 35; Hutchinson, 1949, p. 15; Ghiselin, 1952, p. 44-45; Vernon, 1970; Gowan, 1977, p. 78; Rothenberg, 1979, p 184; cf. Krippner & Hughes, 1970, p. 42).

Although Mozart described the imagery using a visual simile, "I can survey it like a picture or a beautiful statue," this seems to be a reference to the imagistic quality of the reported experience and not an indication of the visual modality. The imagery was reportedly auditory, not visual. Mozart wrote, "Nor do I hear in my imagination the parts successively, but I hear them, as it were, all at once." The report that Mozart perceived the parts of the composition all at once is intriguing considering the duration of real time that a musical composition represents. It may have been for that reason that Mozart elected to use the visual simile: because the reported auditory imagery was perceived all at once in the way that visual information is usually perceived, "at a glance." It may seem unusual to "hear" an entire musical composition in an instant, but Mozart was certainly not the usual sort of person. In a completely separate but related example, the scientist Omar Snyder reported an experience involving a similar chronological condensation of time (see Snyder under primary data above).

Mozart wrote that his "ideas flow best and most abundantly" on any of several occasions, but specifically at times when he reported to have been happy, alone, and seemingly relaxed or at least undisturbed. He mentions riding in a carriage, walking, and "during the night when I cannot sleep," all of which have elsewhere been cited here in connection with reported mental imagery experiences. Mozart conspicuously excludes times when he was asleep, but he did write that "All this takes place in a pleasing lively dream." This reference to a "dream" is not entirely clear, but possibly indicates a waking dream, like a daydream; at the very least it suggests an imagery experience. Mozart's report that the experiences were accompanied by an affective state, in this case a positive one (exceeding delight) may further suggest a dream-like experience, and that they was strong intrinsic motivation for this behavior (see Einstein, part 1 under primary data above).

The statement that, "Whence and how they come, I know not," suggests that Mozart had no control over the conception of these new ideas, like Dodge (see above). He also wrote that the ideas can never be forced, echoing Petrie's comment (see above), even though they were working on vastly different goals. However, once new ideas had occurred, Mozart described great facility with developing them into compositions. His statement that "What has thus been produced I do not easily forget," suggests that it was the (reported) perception of mental imagery that caused more lasting impressions to form. Possibly this was the result of having perceived the compositions as images, specifically in the auditory modality although possessing certain characteristics usually associated with the visual mode.

Though Mozart did not say specifically that the initial ideas which seemed to represent the first insight stage were imagistic, but there is a silent implication in his report that they were. Mozart's report that, "it rarely differs on paper from what was in my imagination," suggests that the perceptions of mental imagery represented both the development (saturation) and the completed compositions (or illumination). The report also suggests that he experienced no difficulties whatsoever translating his reported perception on paper. What Coleridge would have given for that ability!

4.7.41 Richard Wagner

The prelude to Das Rheingold reportedly occurred to Wagner in conjunction with a mental image.

> After a night spent in fever and sleeplessness I forced myself to take a long walk through the country. It looked dreary and desolate. Upon my return I lay down on a hard couch. Sleep would not come, but I sank into a kind of somnolence, in which I suddenly felt as though I were sinking in swiftly flowing water. The rushing noise formed itself into a musical sound, the chord of E flat major, whence developed melodic passages of increasing motion. I awoke in sudden terror, recognizing that the orchestral prelude to *Das Rheingold*, which must have been long lain latent within me, had at last been revealed to me (from Harman & Rheingold, 1984, p. 32; cf. Hutchinson, 1949, p. 30; Starker, 1985, p. 95).

Wagner reported that the imagery occurred while he was laying "down on a hard couch." Clearly he was exhausted and trying to get to sleep. Possibly it was the hardness of the couch that prevented him from falling asleep, like Kekule's experience that reportedly occurred while he was sitting in a chair (see primary data above). Perhaps, as Mozart described (above), not being able to sleep facilitated the flow of ideas, although the report that he "sank into a kind of somnolence" suggests he may have been closer to sleeping than Mozart suggested, possibly indicating a hypnagogic experience.

Wagner's description of "the rushing noise" developing into "melodic passages" clearly indicates perceptions in the auditory modality. There is no reference to visual imagery; however, Wagner described that he "suddenly felt as though (he) were sinking in swiftly flowing water," ostensibly indicating tactile/kinesthetic imagery. These reported sensations seem to further indicate a hypnagogic experience, perhaps similar to that reported by Kekule (see primary data above).

Wagner's report that he "awoke in sudden terror" could be a reference to being wakened out of the reported imagery experience, or may suggest that he had actually fallen asleep, perhaps indicating he had experienced a sleeping dream. The interpretation of this reported experience as a dream is not inconsistent with the nature of the imagery he described. Furthermore, the negative affective quality ("terror") that he reported seems unrelated and may relate to the dream quality. In either case it emphasizes that Wagner was not in an ordinary waking state of consciousness when the reported imagery occurred. The reported imagery seemed to have occurred spontaneously, and developed without apparent effort or conscious direction. He made no indication that he had caused or altered the melody in any deliberate way.

Like Coleridge's poem, Wagner's prelude was realized in its completed form in the reported mental imagery. Wagner reported that it "must have been long latent within me" suggests he had worked on composing the prelude previously, and that the first insight, as well as the saturation and incubation had already been achieved. The reported imagery seems to have been involved exclusively in the moment of illumination.

4.7.42 Guiseppe Tartini

Guiseppe Tartini, the famous composer and also the inventor of the violin bow, reportedly had a dream that provided the immediate inspiration his most famous composition. In the dream:

> Tartini sold his soul to the Devil, and it occurred to him in his dream to hand his fiddle to the devil to see what he could do with it. "But how great was my astonishment when I heard him play with consummate skill a sonata of such exquisite beauty as surpassed the boldest flights of my imagination. I felt enraptured, transported, enchanted; my breath was taken

> away, and I awoke. Seizing my violin I tried to retain the sounds I had heard. But it was in vain. The piece I then composed, the *Devil's Sonata*, was the best I ever wrote, but how far below the one I had heard in my dream!" (from Ellis, 1915, p. 276-7; see Porterfield, 1941, p. 91; MacKenzie, 1965. p. 126; Harman & Rheingold, 1984, pp. 36-7; cf. Starker, 1985, p. 94).

Like Wagner, this was an entirely isolated incident for Tartini, who reported that he was completely asleep at the time when the reported imagery occurred. Tartini described mental imagery in both the auditory and the visual modalities, the auditory images (not surprisingly) providing the prelude itself, which Tartini reported to have "heard."

As with Mendeleev and Hilprecht (see above), Tartini recognized the significance of the imagery immediately even though he was asleep at the time, and woke himself up immediately to reproduce the sounds (auditory images in the dream). Ironically and perhaps tragically, Tartini described the composition he wrote upon awakening as his best, but "far below the one I had heard in my dream," suggesting that the auditory images were not the same as the final composition. Although mental imagery reportedly provided the inspiration, there were changes that occurred in the translation from the imagery to the sonata. The imagery seems to have functioned as the first insight for Tartini's composition, but the remainder was worked out subsequent to this reported experience and there is no further report of mental imagery involved. The report that he "felt enraptured, transported, and enchanted" suggests a compelling positive affective quality was involved.

4.7.43 Hector Berlioz

One night while he was sleeping, Berlioz reportedly had the inspiration for a new symphony. He got up and began to write it down, but his desperate financial situation caused him to reconsider. Berlioz wrote:

> If I begin this bit, I shall have to write the whole symphony. It will be a big thing, and I shall have to spend three or four months over it. That means that I shall write no more articles and earn no more money, and when the symphony is finished, I shall not be able to resist the temptation to have it copied (which entails further expense), and then of having it played. I shall have a concert, and the receipts will barely cover the cost. I shall lose what I have not got. The poor invalid will lack necessities, and I shall be able to pay neither my personal expenses nor my son's fees when he goes on board ship. These thoughts made me shudder, and I threw down my pen saying: "Bah, tomorrow I shall have forgotten the symphony." But the next night I heard the allegro clearly and seemed to see it written down. I was filled with feverish agitation. I sang the theme. I was going to get up, but the recollections of the day before restrained me. I steeled myself against the temptation and clung to the thoughts of forgetting it. At last I went to sleep, and the next day upon awakening all remembrance of it had indeed gone forever (from Hutchinson, 1949, p. 65).

Berlioz reported to have experienced the dream on two successive nights while he was asleep. He reported both to have "heard the allegro clearly, and seemed to see it written down," indicating both auditory and visual imagery. The report that Berlioz "sang the theme" may be misleading. He was apparently still lying down at the time: He wrote, "I was going to get up, but . . ." Lying down is not conducive to singing. He may in fact still have been sleeping, and the act of singing being part of the dream. This would suggest that tactile/kinesthetic imagery was involved. If he had still been sleeping, that would also help to explain why (with some insistence) the theme was forgotten so quickly and thoroughly, never to return; though as a tragic irony he remembered having had the dream!

Although in the end he reportedly elected not to record the musical imagery he had perceived, his statement that he recognized a completed composition during his dream and (initially) caused himself to get up and write it down is similar to the incidents reported by Mendeleev, Hilprecht, and Tartini (see above).

The mental image of singing is qualitatively different from that of hearing, and indicates the involvement of a kinesthetic component. Perhaps the interaction of three different modalities: auditory, visual, and kinesthetic, all expressing different aspects of the same music contributed to the experience of the symphony as it occurred, but it does not seem to have helped Berlioz to record it or to maintain the image for very long. At last the images were dictated by his overriding financial preoccupation. Possibly his financial burden was the cause of his "feverish agitation," but this negative affective factor could have been related to the dream itself. He reported no other incidents involving mental imagery.

The report suggests that his reasoning processes were active: They were active enough for him to talk himself out of recording the music. How tragic, when he had reportedly seen the score written as a visual image in his imagination, and could have (ostensibly) transposed the notes directly onto paper without apparent difficulty and thereby have created a lasting record (document). The dream reportedly carried the inspiration (first insight) for a new symphony, Berlioz recognized even at the time that the whole symphony would have required much greater effort to develop. This case does not actually represent a creative production, but rather a failed opportunity. Nevertheless, it is included as a reminder of the potential fragility of creative behaviors.

4.7.44 The Eskimo

The report of the man referred to as simply "the Eskimo" does not involve a significant creative product either, but it does suggest a remarkable case of mental imagery abilities. Galton reported:

> Other living races have the gift of drawing, but none more so than the Eskimo. The Eskimos are geographers by

> instinct, and appear to see vast tracts of country mapped out in their heads. From the multitude of illustrations of their map drawing powers, I mention one included in the journals of Captain Hall, published in 1879 by the United States Government. It is the facsimile of a chart drawn by an Eskimo who spoke no language besides his own uncouth tongue, was wholly uneducated according to our modern ideals, and lived in a savage fashion. This man drew from memory a chart of the region over which he had at one time or another gone in his canoe. It extended from Pond's Bay to Fort Churchill over a distance of 1,100 miles, the coast being so indented by arms of the sea that its length is six times as great. On comparing this rough Eskimo outline with the Admiralty chart of 1870, their accordance is remarkable. I have seen many route maps made by travelers and I can confidently say that I have never known of any traveler, white or brown, civilized or uncivilized, in Africa, Asia, or Australia, who, without surveying instruments, and trusting to memory alone, had produced a chart comparable in extent and accuracy to that of this Eskimo (Galton, 1883, p. 72).

In spite of several inaccurate and sometimes offensive references about this man's character and his ethnic culture, Galton manages to portray a truly remarkable individual. The Eskimo's physical endeavor is gargantuan, having reportedly traveled, by canoe, "a distance of 1,100 miles, the coast being so indented by arms of the sea that its length is six times as great." Being without maps, or compass, their navigational skills must have been largely determined by their memory of the coastal geography. This man's memory reportedly coincided with the extent of the coastline he had traveled. The report that he drew a chart of this entire region from memory suggests the geographic information was stored iconically as an image in the visual modality. Although Galton neglected to specify, the report that the Eskimo's drawing represented a chart presumably indicates that it depicted an overhead view. It is an intriguing tangent to the study of mental imagery that diverse peoples have independently developed aerial perspective as a map making device beginning well before flying machines were ever imagined. This early mental map-making ability seems to be a function of visual imagery.

Although even in Galton's report it is obvious that the man did speak and had his own language, there is no indication as to what role language may have played in the development of his mental imagery ability. Navigational skills may have been passed from one generation to the next, possibly through verbal means; but it is difficult if not impossible to construct a map of natural geographic formations from words. Furthermore, this man's ability was reportedly unique, even among the Eskimo navigators that the Americans explorers had encountered, suggesting his skills had independently developed beyond average levels. The fact that navigational skills were required for the survival of the entire community suggests that the ability to recall visual information may have developed largely out of necessity.

Chapter 5

5.1 Results of analysis

This study revealed a total of 44 incidents involving the reported perception of mental imagery in conjunction with creative problem solving (i.e. discoveries, inventions, etc.). The primary data, representing scientific discoveries reported by the subjects themselves, include 15 incidents from 14 different scientists and inventors. There were twenty-nine additional incidents that were either reported by second person accounts, or they were not related to specific scientific discoveries or inventions. The secondary data include 29 incidents involving 27 different subjects; 18 were reported by the subjects themselves, and 11 by biographers or historians. Eight incidents from the arts were also revealed.

In addition to the narrative analysis, following each factor there is a numerical analysis for faster reference. The numbers summarize the results according to: a) the number of incidents from the primary data (first person reports), b) the combined number of incidents from the primary and secondary data, and c) incidents that are possible examples but are less clearly established than those represented in the combined set (b). The numbers are arranged according to the following form: (a;b+c). Incidents not included in the calculations that are presented in the discussion as related but tangential references are set off by parentheses.

1. Possible causes for the reported perception of mental imagery. Several factors were reported that may have contributed to the reported perception of mental imagery in certain cases.

Walking (3;3+1). Watt, Tesla, and Snyder all reported to be walking at the moment when the mental imagery reportedly occurred. Watt and Tesla were both outdoors, but Snyder was walking down the hallway at work. Watt was alone, while Tesla was with a friend.

Watt, Tesla, and Snyder all reported mental imagery in conjunction with the solution to mechanical engineering problems. Furthermore, the reported imagery in all three incidents occurred suddenly and carried the solution (illumination). Snyder and Tesla reported that the inventions were instantly complete, apparently with little or no conscious effort or direction, although Tesla also reported to have frequently developed inventions as mental images. Watt described his conscious development of the invention as a mental image. The illuminating moment had reportedly occurred by the time each of them had finished their walk.

Mozart reported that "walking after a good meal" was one of three ways he stimulated his flow of ideas (see also riding in a carriage and insomnia below), however his report did not include reference to any specific incidents.

(The poet A. E. Housman reported that walking facilitated his creative process.

> Having drunk a pint of beer at lunch--beer is a sedative to the brain, and my afternoons are the least intellectual portion of my life--I would go out for a walk of two or three hours. As I went along, thinking of nothing in particular, only looking at things around me and following the progress of the seasons, there would flow into my mind, with sudden and unaccountable emotion, sometimes a line or two of verse, sometimes a whole stanza at once, accompanied, not preceded, by a vague notion of the poem which they were destined to form part (Housman, 1933; from Ghiselin, 1952, p. 91; Rugg, 1963, p. 5; cf. Sinnott, 1959, p. 23-4).

Like Mozart, Housman described the practice specifically after a meal, however Housman also made a point to include the additional pint of beer. Housman's report is also interesting to this study because of his reportedly sudden recognition's of "whole stanza(s) at once," a process that may be related to the condensation of entire compositions into an instant reported by Mozart, or the drawn out process that was reportedly perceived by Snyder in an instant (see condensation of time below). There is no specific indication that Housman perceived the lines of verse in conjunction with mental imagery, but presumably either auditory and/or the visual imagery could have been involved.)

Riding in a bus or carriage (2;3+1). Kekule, Yellot, and Blanchard were each riding in a bus or carriage at the time the imagery reportedly occurred. Blanchard was driving a carriage, apparently alone. Kekule and Yellot were each on a bus. Kekule reported that it was late and the streets were empty so presumably there were very few people on the bus, if any. Yellot reported that his bus was crowded. Presumably they were each sitting down at the time (see sitting below), though perhaps Yellot was forced to stand because of the crowd. In all three reports the subjects were on their way home when the imagery reportedly occurred.

Yellot and Blanchard reported discoveries involving mechanical inventions. They reported to have realized the completed solution in a direct way, and immediately recognized their solutions were correct. The incidents were apparently isolated with no further reports of mental imagery from either person. Kekule on the other hand reported not an invention but a discovery in the field of molecular chemistry. With Kekule's discovery the solution emerged slowly and involved repeated imagery experiences, always representing the abstract dancing atoms. Two of Kekule's reports are included in the primary data above: the one involving the bus home ride through deserted streets, and the other about sitting in front of a fire (see Kekule under sitting, hypnagogic experiences, and pareidolia below). Mozart wrote that riding in a carriage was one of three places that reportedly facilitated his creative process, however he provided no specific examples (see Mozart under walking above and insomnia below).

Sitting (2;2+4). Kekule and Einstein (part 1) both reported mental imagery experiences to have occurred while they were sitting down. Einstein was sitting in a chair at work. Kekule was sitting in a chair at home in front of a fireplace. Both cases involved discoveries about the natural world: physics for Einstein, and chemistry for Kekule.

Einstein and Kekule both reported multiple mental imagery experiences related to scientific discovery. Kekule reported multiple occurrences, all leading to a single discovery. There are reports of mental imagery related to several (4) different discoveries by Einstein, but only one where he reported that he was sitting down at the time. Kekule also reported imagery to have occurred in another incident while he was riding on a bus, and presumably sitting down (the bus could not have been very crowded because the streets were empty).

Yellot reported to have experienced mental imagery while he was riding in a bus, possibly sitting down (though the bus was crowded and he may have been forced to stand). Blanchard reported mental imagery to have occurred while he driving home, probably on a carriage, which would indicate he was sitting also. Coleridge was in a chair when he reported mental imagery to have occurred. Mozart's report that riding in a carriage was one of his (3) preferred places to stimulate his ideas/images presumably suggests he was sitting in the carriage (see Mozart also under walking and riding in a bus or carriage above, and insomnia below).

Lying down (2;3+9). Evans, Watson, and Wagner all wrote that they had reportedly experienced mental imagery while they were lying down. They were each at home during these incidents. Evans and Watson were lying in their beds.

There are indications that hypnagogic experiences may have been involved in each incident (see hypnagogic experiences below). Evans reported that the experience was accompanied by "much mental anxiety," presumably indicative of a negative or unpleasant (disquieting) affective state, perhaps suggesting a hypnagogic experience. Watson reported that the experience began after midnight and lasted for over two hours but describes a state of happiness and pleasure qualitatively different from Evans' reported state of anxiety. Nevertheless, the seemingly undirected quality of the reported mental images "whirling in front of (his) closed eyes" suggests a hypnagogic experience may have been involved. Wagner reported specifically that he was unable to sleep, took "a long walk through the country," and returned home where he laid down on hard couch. Wagner's entire description suggests he experienced a negative affective state, possibly like Evans, that was unconnected (disassociated) with any apparent cause. Although Wagner reported that he was not asleep, there is a dream-like quality to the imagery he described that may indicate a hypnagogic experience was involved here as well.

Mendeleev, Hilprecht, Bohr, Watt (part 2), Howe, Tartini, and Berlioz were all reportedly sleeping and were most likely lying down.

Mozart reported that ideas/images "flow best and most abundantly" on three occasions including "during the night when I cannot sleep," suggesting that he may have been lying down at the time. Hawking reported that he was getting into bed but not specifically lying down when he experienced an illumination.

Hypnagogic experiences (1;3+2). Kekule, Coleridge, and Wagner described hypnagogic experiences. Kekule described two related hypnagogic experiences. One occurred while he was riding home on a bus (see riding in a bus or carriage above), and the other occurred while sitting at home in front of a fire (see sitting above). Kekule described both incidents as "reverie" experiences, seemingly consistent with the interpretation of hypnagogic experiences as used by this study. The first incident on the bus was reportedly an improvement on earlier related perceptions, causing renewed effort in his work but not resulting in any specific progress toward a solution. During the second experience, sitting in front of the fire he reported to have experienced the illumination of the discovery. Both incidents involved basically similar images of dancing atoms. The second incident reportedly represented not significantly different images but improved observational abilities, enabling him to perceive more than on previous occasions.

Coleridge reported a dream-like sleep of the senses that is also considered below under intoxicants because it was artificially induced; nevertheless, his report is consistent with those of hypnagogic experiences. Wagner also reported that he experienced imagery that was fantastic in nature while he was lying down. Although Wagner reported that he was unable to sleep (see insomnia below), he was very tired and the report suggests that he may have fallen into a light sleep or some other sort of hypnagogic state when the imagery occurred.

Hypnagogic experiences may have been involved in the incidents cited by Evans and Watson who reported that they were awake, but they were also lying down at the time and described affective states in conjunction with mental imagery experiences.

(Edison reportedly used hypnagogic experiences as an intentional way to facilitate his process of invention. According to one of his research assistants:

> When stumped by something, (Edison) would stretch out in his Menlo workshop and, half-dozing, have the idea come from his dream mind to help him around the difficulty (from Porterfield, 1941, p. 94).

Hadamard reported he had only just woken up, possibly indicating a hypnopompic experience, but there is nothing in his description to suggest the fantastic sort of imagery, often accompanied by an affective quality that was associated with the hypnagogic examples.)

<u>Sleeping</u> (2;7+4). Mendeleev, Hilprecht, Bohr, Watt (part 2), Howe, Tartini, and Berlioz all reported that illuminating experiences occurred spontaneously while they were asleep. In each case some part of the solution was specifically represented in a dream image. Mendeleev and Bohr reported to have perceived mental imagery that represented unobservable natural phenomena. Watt, Howe, and Hilprecht had each been struggling with their respective problems prior to the reported incidents. Mendeleev reported that he went to bed exhausted after struggling with the problem he was working on (see exhaustion below). There is no indication that Bohr had previously attempted to solve that particular problem, although presumably it was not entirely unfamiliar. The reports about Tartini and Berlioz suggest they had perceived the music for the first time as it occurred in their dreams, although with Berlioz the same image reportedly reappeared during the consecutive night. Watt reportedly experienced mental imagery in a second incident, although that incident reportedly occurring while he was talking a

walk (see walking above) and involved an entirely different set of circumstances.

Hadamard reported having experienced an illumination "at the very moment of sudden awakening." Coleridge, Kekule, and Wagner described dream-like images that suggests they could have fallen asleep as well.

Exhaustion (2;3+0). Mendeleev, Hilprecht, and Wagner each reported the were tired to the point of exhaustion when the reported imagery occurred. Mendeleev and Hilprecht reported they were exhausted and had fallen asleep, the imagery having occurred in the dreams that ensued (see sleeping above). Wagner was lying down and trying to get to sleep (see insomnia above).

(Watson reported that he was awake while laying in bed "for over two hours past midnight," although he reportedly was content and did not report to be specifically tired.)

Getting into bed (1;1+0). Hawking reported he was getting into bed, and that in the process he "started to think about black holes." His disability caused the act of getting into bed to be "a rather slow process," but the discovery seemed to have occurred before he was able to lie down.

Outdoors (2;2+1). Watt and Tesla were both outdoors when they reported to have experienced mental imagery. Both described walking through a park like setting (see walking above), though Watt was alone (see alone below) and Tesla was with a friend (see accompanied below). The result of their reported experiences in each case was the production of designs for a revolutionary mechanical invention.

The report that Newton was in his mother's garden when he conceived his theory of gravitation indicates that he was also outdoors, but there is no specific description of Newton having perceived mental imagery while he was outdoors.

At work (3;3+0). Einstein (part 1), Snyder, and Watson were all at work when they reportedly experienced moments of illumination. Einstein and Snyder both suggested that they were not thinking about the problem at the time the solution occurred: Einstein was sitting in a chair, and Snyder was walking down the hall. Watson was in his lab and working with models, suggesting he was thinking about the problem (see below) when he realized the solution.

Intentionally developed skill (2;3+0). Tesla, Hawking, and Poincare all reported having intentionally developed mental imagery skills and specifically in response to physical or psychological impediments. Tesla developed his abilities to compensate for the sudden appearance of images that tormented him from childhood (see Tesla under hallucinations above). Hawking turned to relying on mental imagery because physical handicaps prevented him from writing or even talking. Poincare reported developed several unusual abilities in response to handicaps caused by a case of childhood diphtheria.

Hereditary/Genetic (1;1+1). Tesla reported that his brother suffered from the appearance of tormenting images similar to his own. There is no report of Tesla's brother having developed mental imagery abilities to compensate for this affliction, but the report that they both experienced spontaneous mental imagery suggests it may have been the result of traits that were passed genetically.

Galton's report that "The Eskimos are geographers by instinct" suggests their ability may also have been passed genetically. The integral role of navigation to their survival suggests a possibility that mental imagery skills related to navigation were either passed genetically, or taught from one generation to the next. Either case poses fascinating possibilities.

One time experiences (5;11+0). Specifically one time isolated experiences of mental imagery were reported by Mendeleev, Hilprecht, Hadamard, Yellot, Snyder, Blanchard, Bohr, Howe, Ernst, Wagner, and Tartini. All of them reported the mental imagery to have occurred in an entirely spontaneous and unintentional way. Mendeleev, Hilprecht, Hadamard, Yellot, Snyder, Blanchard, Howe, and Wagner had each been working specifically on the problems that were reportedly revealed through mental imagery prior to those experiences. Ernst and Tartini reported specifically new ideas resulting from their experiences. Bohr made no reference to having worked on solving the structure of the atom prior to his discovery, reportedly in a dream.

Multiple imagery experiences (4;18+4). There are reports of multiple incidents of mental imagery involving Kekule, Einstein, Tesla, Feynman, Watt, Faraday, Cray, Galileo, Newton, Petrie, Dodge, Thompson, Forshee, Wood, Didion, Da Vinci, Mozart, and Berlioz. There are specifically two incidents reported by Kekule and Berlioz each, and two incidents reported about Watt, Galileo, and Newton. The others reported about themselves that mental imagery was a familiar aspect of their creative process, presumably having occurred three or more times. There are four separate incidents reported about Einstein alone, two by Einstein himself.

There is also a possibility that the mental imagery experiences reported by Evans, Nasmyth, Watson, and Chrysler were not isolated events. Evans, Nasmyth, and Chrysler leave open the possibility that they had considered the reported imagery in conjunction with their discoveries more than once or twice. Watson's analysis by use of models and visual forms also suggests he may have been developing models as mental images throughout his creative process.

Alone (4;8+1). Watt, Kekule, Watson, Hawking, Blanchard, Coleridge, Mozart and Wagner were each alone when they reported an imagery to have occurred. Kekule was sitting alone in front of the fire. Watt was walking alone when he reportedly redesigned the steam engine in a mental image. Mozart reported specifically that he preferred to be alone when he was creating. Coleridge reported that the distraction of a person calling for him was enough for him to forever forget the majority of the poem contained within his reported mental imagery experience. Blanchard was driving alone in a carriage. Watson and Wagner were each lying down, and Hawking was getting into bed; all were apparently alone.

The report of Newton's discovery while in his mother's garden may indicate that he was alone as well.

(Presumably the subjects in several other incidents reported here were alone as well, especially some of the reports where the person was sleeping at the time, but there is no clear indication in the reports that this was the case.)

Accompanied (1;1+0). Only Tesla reported that he was accompanied by a friend when an invention occurred to him as a mental image. They were walking in a park and reciting poetry.

Thinking about the problem when the solution occurred (2;2+3). Watt and Watson were both specifically thinking about their respective investigations at the time when the mental imagery reportedly occurred. Watt reported a high degree of control over the images whereas Watson's whirling adenine residues seemed undirected.

Mendeleev and Hilprecht were asleep when the imagery reportedly occurred (see sleeping above), but they were reportedly working on their discoveries immediately prior to going to sleep on those nights. Furthermore, they both were reportedly exhausted. Coleridge also reported that he was focused on reading lines that were closely related to his poem at the moment when his dream-like imagery reportedly occurred.

Not thinking about the problem when the solution occurred (6;7+4). Kekule, Hadamard, Tesla, Einstein (part 1), Yellot, Snyder, and Wagner were all preoccupied and not thinking about their respective problems when the solution reportedly occurred. Kekule reported falling into a reverie, once on a bus and once in front of a fire (see hypnagogic experiences, riding in a bus or carriage, sitting, and pareidolia above). Wagner was exhausted and trying to fall asleep. Hadamard's solution occurred upon suddenly being awakened from sleep. Like Kekule, Yellot reported his experience to have occurred on a bus, but the bus was crowded unlike Kekule's which was deserted. Einstein and Snyder were both at work: Einstein was sitting down, whereas Snyder was walking down the hall. Tesla and Snyder were each walking (see walking above). Tesla was with a friend (see accompanied above).

Bohr, Tartini, and Berlioz were asleep when the reported experiences occurred. Tartini and Berlioz both indicated that their dreams represented entirely new musical compositions, suggesting that they had not previously worked on them, and could not have been thinking about them (unlike Mendeleev and Hilprecht who had been working on their problems right up until the moment they went to bed on those nights). Bohr also made no mention of thinking about his problem prior to his reported dream image.

Howe and Watt (part 2) were both sleeping when inventions were reported to have occurred, but they had previously worked on those problems prior to their reported dream experiences. Perhaps prior consideration did contribute to their reported mental imagery experiences, but there is nothing to specifically suggest that they had been thinking about those problems immediately before going to sleep on the nights when the reported imagery occurred (as Mendeleev and Hilprecht described); it is possible that they were not.

Kekule and Mozart may also have been otherwise distracted at the times when they reported mental imagery to have occurred. Each reported that these were not single, isolated experiences either.

Kekule reported two specific incidents involving hypnagogic experiences (see above), while Mozart indicated that his process involved several possible circumstances, none of which suggests they involved directly thinking about the problem (see walking, riding in a bus or carriage and insomnia above).

Consciously directed (4;9+6). The reports of Evans, Nasmyth, Watt, Tesla, Petrie, Thompson, Cray, Mozart, and the Eskimo suggest they were able to consciously direct or construct the reported mental imagery. Mozart reported that there were only certain situations that were conducive to this process, but the accounts of all the rest suggest they were able to methodically construct the reported perceptions at will. There was a second incident involving Watt (part 2) where he invented the new method for making lead shot, reportedly as the result of a mental image in a dream (see not consciously directed below).

The reports of Einstein, Hawking, Galileo, Newton, Maxwell, and Poincare may also describe consciously directed imagery. Each seemed to use imagery in a purposeful way to describe their theories, suggesting the images had been intentionally developed. Although Einstein (part 1) also described the sudden and spontaneous occurrence of mental imagery, there are thought experiments he described involving scenarios that seem to be more consciously orchestrated, perhaps as in traveler on a beam of light looking into a mirror (part 3), or the tram traveling at the speed of light away from a clock (part 4).

Not consciously directed (6;13+1). Mendeleev, Hilprecht, Kekule, Hadamard, Yellot, Watson, Bohr, Watt (part 2), Howe, Coleridge, Wagner, Tartini, and Berlioz reported to have experienced mental imagery that occurred spontaneously, and though it was not consciously directed the imagery was reported to have facilitated the discovery process. Bohr, Howe, Watt (part 2), Hilprecht, Mendeleev, Wagner, Tartini, and Berlioz were all reported to be sleeping when the imagery occurred in a dream. Hadamard was woken up suddenly. Kekule, Watson, and Coleridge were in a dream-like hypnagogic state. Yellot was riding on a bus.

Dodge reported that "When working out a new device mental pictures present themselves to my mind more rapidly that I can record them on paper. The rapid stream of consciousness process Dodge described suggests they also were beyond his ability to control, or he would presumably have slowed them down, perhaps in the way that Petrie was reported to have "visualized only that part of the slide rule with which he is at the moment concerned."

Positive affective quality (3;5+0). Tesla, Einstein (part 1), Watson, Mozart, and Tartini all described positive affective qualities associated with reported mental imagery experiences. Tesla wrote that the reported experience represented "a mental state of happiness as complete as I have ever known." Einstein described his experience (part 1) as "the happiest though in my life." Watson reported mental imagery to have occurred as he "happily lay awake." Mozart wrote about his reported experiences that "What a delight this is I cannot tell!" Tartini wrote that he "felt enraptured, transported, and enchanted."

Negative affective quality (4;7+0). Evans, Kekule, Tesla, Yellot, Howe, Wagner, and Berlioz all described negative affective qualities associated with reported mental imagery experiences. Evans reported to have experienced "much mental anxiety" associated with his reported mental imagery. Kekule reported that "the image whirled scornfully before my eyes." In addition to Tesla's reference to his reported imagery experience involving the AC generator as the happiest state he had ever known (see positive affective quality above), he described being tormented by the sudden and uncontrollable appearance of images during his childhood. Yellot reported his invention to have occurred while he was thinking about other matters that were "disturbing" him. In Howe's dream he was menaced by savages who threatened him with spears. Wagner reported that he "awoke in sudden terror." Berlioz reported that he was "filled with feverish agitation."

Insomnia (0;2+0). Mozart and Wagner both reported mental imagery associated with incidents of insomnia. Wagner reported imagery to have occurred as after a long night of sleeplessness. He was lying down (see above) after being unable to fall asleep the entire night. Although the report suggests that he may have drifted into sleep or at least a hypnagogic state at some point, this occurred only after many hours of restless insomnia during which he reportedly could not sleep. Mozart provided no specific examples but reported that sleeplessness stimulated his ideas/images. Wagner and Mozart's reports indicate that the auditory imagery had performed the critical function in their discovery process.

(Watson and Kekule both reported to have worked late into the night, though reported no specific trouble with falling asleep. Poincare, who was presented in the secondary data above reported to have found a major discovery one night when he could not fall asleep

> One night I took some black coffee, contrary to my custom, and was unable sleep. A host of ideas kept surging in my head; I could almost feel them jostling one another, until two of them coalesced, so to speak, to form a stable combination. When morning came I had established the existence of one class of Fuchsian functions. I had only to verify the results, which only took a few hours (Poincare, 1913; from Taton, 1962, p. 21; see Montmasson, 1932, p. 79 ff.; Hadamard, 1945, p. 13; Ghiselin, 1952, p. 36; cf. Sinnott, 1959, p. 23; Rugg, 1963, p. 4; Koestler, 1964, pp. 115-6; May, 1975, p. 63; Arieti, 1976, p. 268; Shepard, 1978, p. 139).

Although he was reportedly awake, Poincare's description of ideas surging and jostling suggests that they were not consciously directed. Poincare did report that he was not used to drinking coffee at night, and perhaps that had some effect on the experience. Caffeine is classified as a stimulant, but there is evidence that stimulants like cocaine or metha-amphetamines for example can result in hallucinations. On the other hand, he may at some point have briefly fallen asleep or slipped into a hypnagogic state. Although Poincare's testimony above did not suggest imagery was involved, it has a quality that is reminiscent of Kekule's gamboling atoms, and may also be related to Watson's whirling adenine pairs.

Henry Wordsworth Longfellow reported the creation of a poem to have occurred during a sleepless night.

> Last evening . . . I sat till twelve o'clock by my fire, smoking, when suddenly it came into my mind to write the "Ballad of the Schooner Hesperus," which I accordingly did. Then I went to bed, but could not sleep. New thoughts were running in my mind, and I got up to add them to the ballad. I felt pleased with the ballad. It hardly cost me any effort. It did not come into my mind by lines, but by stanzas (from Harman & Rheingold, 1984, p. 35).

In addition to the reported insomnia, Longfellow's report that he was sitting, that he was by the fire (pareidolia), and that he was smoking may each have contributed to his reported experience. The description of lines coming not "by lines but by stanzas" suggests a condensation of information similar to the experience reported by Mozart.)

<u>Intoxication</u> (0;1+0). Coleridge reported having taken opium immediately prior to his dream-like experience. Opium is not considered a hallucinogenic but is a profound narcotic and was probably responsible for his state of mind at the time: "a sleep of the senses." Perhaps he had fallen asleep or into a hypnagogic state.

<u>Gazing fixedly</u> (0;0+2). Although there were no reports of specific discoveries resulting from "gazing fixedly" as Leonardo

wrote, both he and Ernst reported they had experienced mental imagery to have occurred as a result of this behavior. (This experience may be related to pareidolia, suggesting a connection to Kekule staring into the fire; see below.)

Pareidolia (0;0+1). Although Kekule reported that he was staring into a fire when the second mental imagery incident occurred, the imagery was seemingly similar to the earlier incident that occurred while he was on the bus. Perhaps pareidolia was not involved; or possibly there is a connection between pareidolia and gazing fixedly such that staring out the window of the bus was capable of stimulating mental imagery experiences similar to staring into a fire. (That may imply that Leonardo and Ernst's reports were related to Kekule's as well.)

2. What perceptual modalities were involved in the reported mental imagery?

Visual (13;37+0). Evans, Nasmyth, Watt, Mendeleev, Hilprecht, Kekule, Hadamard, Tesla, Yellot, Snyder, Watson, Feynman, Hawking, Blanchard, Bohr, Howe, Faraday, Chrysler, Coleridge, Tartini, and Berlioz were all reported to have perceived visual mental imagery in conjunction with specific discoveries or inventions. Petrie, Dodge, Thompson, Forshee, Wood, Cray, Didion, da Vinci, and Ernst reported to have used visual imagery to facilitate creativity, however descriptions of specific imagery experiences were unfortunately omitted. The report of the Eskimo's abilities suggest that he also perceived mental imagery in the visual mode. Galileo, Newton, Maxwell, Poincare, and Einstein (parts 3 & 4) used visual mental images to describe concepts but did not specifically report to have conceived those concepts as mental images.

Tactile/Kinesthetic (1;2+8). Einstein (part 1) and Wagner both reported to have experienced tactile/kinesthetic sensations associated with mental imagery. Einstein's first thought experiment (part 1) involved two elements: falling through the air, and (not) feeling the weight of his own body. Einstein did not specifically describe the mental imagery modality through which his discovery was made, but the imagery he described suggests he may have perceived images like the feel of air resistance (wind) against his skin, or perhaps the feeling in the pit of your stomach that accompanies falls of a certain magnitude. The way that he would have perceived weightlessness as a mental image is not entirely clear, but the report suggests that tactile and/or kinesthetic sensations were involved. Elsewhere Einstein stated definitively that his thinking was sometimes of a muscular type, perhaps indicating the tactile/kinesthetic modality as in the case considered here (Einstein, part 1).

While Einstein described a scientific thought experiment that occurred to him as he was sitting in the office where he was employed, Wagner reported to have perceived an auditory mental image one night when he was unable to fall asleep, from which a musical composition developed. In addition to the auditory imagery, Wagner also reported the sensation of "sinking in swiftly flowing water." This tactile/kinesthetic component did not represent the music itself, but was reportedly perceived to have initiated the auditory image (E flat major) from which the music ensued. Both incidents reportedly involved the feeling of weightlessness.

Several other incidents may have involved tactile/kinesthetic imagery as well. Kekule described falling into a state of reverie. His description may simply have been a figure of speech, but it may also indicate that a kinesthetic sensation was involved, possibly more closely related to Wagner's experience than to Einstein's.

Watt (part 2) reportedly perceived in a dream to be walking through a shower of lead pellets. Watt's reported imagery may have been primarily visual, but the description suggests he may also have perceived the feeling of being struck by the "heavy rain," indicating the possibility that a tactile component was involved. Similarly, Howe described being dragged by savages in his dream, which could indicate he experienced tactile/kinesthetic sensations, although if he did they were unrelated to the discovery that enabled him to complete his invention. Berlioz reported that he "sang" the theme he had heard in his dream. Perhaps he perceived his voice strictly through auditory mental images, but there may have been a kinesthetic component involved in his perception of singing the notes.

Chrysler and Nasmyth both described tactile sensations as playing a key role in their inventing processes. Although their reports of the inventions included in this study rely heavily on visual mental imagery, they both also acknowledged the significance of the tactile modality. Chrysler wrote, "what I learned through my fingers and my eyes together I never seem to forget." Nasmyth also emphasized the same combination of sensory modalities, "The eyes and the fingers--the bare fingers--are the two principal inlets to trustworthy knowledge" (see discussion of Nasmyth's statement under Chrysler in secondary data above, and also the discussion of Peter Cooper Hewitt in the same location who was known for his capacity with his hands). Watson's use of building blocks to construct models for the DNA structure involved visual <u>and</u> tactile learning processes, possibly contributed to his discovery as well.

Feynman stated that his reported imagery experiences were "all visual," but his description of "this stuff that he tries to collect and to push" (to paraphrase) suggests there may have been a tactile/kinesthetic element involved. His description suggests the perception of a bodily involvement that was not strictly visually oriented.

<u>Auditory</u> (1;5+3). Hilprecht, Mozart, Wagner, Tartini, and Berlioz are reported to have perceived mental imagery in the auditory modality in conjunction with creative accomplishments. Hilprecht, Tartini, and Berlioz each reported that the experiences occurred while they were asleep and dreaming. Wagner was exhausted and trying to get to sleep but seemed to have been

suffering from a case of insomnia (see above). Mozart also reported to have experienced auditory imagery when he could not sleep, and while traveling in a carriage or "walking after a good meal." Mozart, Wagner, and Berlioz reported auditory mental images representing musical compositions. Tartini reported musical content to his perceptions but suggested there may also have been a verbal component. Hilprecht reported that the content of his auditory perceptions was exclusively verbal.

Howe, Bohr, and Coleridge imply that they may have experienced auditory mental imagery, but they made no clear statement about this possibility. Howe and Bohr were both asleep when the perceptions occurred; Coleridge's report of a dream-like state suggests he may have been near to sleep as well. If auditory imagery was involved, the reports suggest that Howe and Coleridge perceived verbal imagery, while Bohr's auditory perceptions were related to "planets whistling as they passed."

Verbal (1;3+2). Hilprecht, Howe, and Coleridge each described verbal content involved in their reported mental imagery experiences. Hilprecht reported specifically auditory perceptions carrying the verbal content. Howe and Coleridge did not specify the modality in which their reported verbal perceptions occurred, and may have been either auditory or visual, or perhaps both.

Tartini may have experienced some verbal exchange in his dream about dealing with the Devil. Berlioz reported to see the music written down, though presumably in a form of musical notation. While musical notation is not a part of language, there are significant similarities between the two: both involve an act described as "reading," and they share formal conventions such as entry and exit points.

Time condensation (1;2+2). Snyder and Mozart both reported to perceive lengthy solutions in an instant of time. Snyder reported to have instantaneously recognized a process that was "drawn out in time," (as his interviewer Shepard described it). Mozart reported to hear the parts to a composition "not successively but all at once."

Hawking and Einstein's investigations sometimes involve the concept of time as a physical property that can be isolated and even frozen. Einstein theorized that at the speed of light time would appear to have stopped; and Hawking proposes that falling into a black hole would produce the same effect.

3. The stage in the creative process at which imagery was reportedly involved.

First insight (1;5+7). Einstein, Didion, Mozart, Tartini, and Berlioz all reported that mental imagery had been involved specifically in the earliest stage in their creative processes, also called the insight or first insight stage. Tartini and Berlioz reported to have heard finished compositions that had never occurred to them before, although Tartini was later unable to match the beauty of the music he had heard, and Berlioz was unwilling to try. Didion and Mozart reported to be able to develop their literary and musical compositions (respectively) as mental images (see intentional control below). Mozart reported that he was often to complete finished scores in this way, writing that "it rarely differs on paper from what was in my imagination." Einstein reported that not only the initial problem but also the final solution and even verification was contained within that moment of first insight.

Possible incidents involving first insights are as follows: Feynman suggested that his creative process began with vague mental images, but did not describe any specific examples. The reports about Faraday's ability to "see" lines of force suggest that perceptions of mental imagery may have served as a first insight similar to Feynman's report. Dodge, Thompson, and Wood all reported mental imagery in conjunction with the first step in their respective creative processes. The report about Cray suggests he begins with a mental image as well. Coleridge made no indication that he had ever considered writing a poem about Kubla Khan until he perceived it in a dream, reportedly in a completed state though he was unable to record more than a fraction of it on paper after being disturbed from his dream-like opium induced state.

Saturation (3;10+2). Tesla, Feynman, Hawking, Chrysler, Thompson, Forshee, Wood, Cray, Didion, and Mozart all reported having developed their inventions as mental images. Reportedly at times they were able to use this method to develop their inventions all the way to the completed design state. Feynman alone among this group admitted that "in the end mathematics can take over and be more efficient." Hawking's research was most closely related to Feynman's, but Hawking made no such comment. Tesla, Chrysler, Thompson, Forshee, Wood, and Cray were all inventors. Didion and Mozart were artists.

Nasmyth's report of mentally observing mechanical structures in operation suggests they may have played a part in the development (saturation) of his invention. He did not report to have altered or manipulated the reported imagery, but his description of "building it up in the mind" suggests an active involvement more closely associated with the saturation than the incubation stage. Dodge also seemed to suggest his inventions were developed through mental images, specifically through the elimination of images. But his reference to that process as the first step creates some ambiguity on this point. Saturation represents the second stage.

Incubation (2;2+0). Kekule and Watson reported to have perceived mental imagery at a point in their research after they had already entered (or perhaps even completed) the saturation stage, but the imagery was perceived as a peripheral byproduct of their investigations and did not serve to further the development of their ideas in any direct or obvious way. Kekule and Watson's reported both suggest that mental imagery was involved in their illumination experiences, but they also reported separate, earlier mental imagery experiences that did not precipitate the solution.

Illumination (11;22+6). Watt, Mendeleev, Hilprecht, Kekule, Hadamard, Tesla, Einstein, Yellot, Snyder, Watson, Hawking, Blanchard, Bohr, Howe, Chrysler, Thompson, Forshee, Wood, Cray, Coleridge, Mozart, and Wagner all reported illuminating experiences to have occurred in conjunction with mental imagery. Mendeleev, Hadamard, Bohr, Howe, and Hilprecht were reportedly asleep at the time. Kekule, Coleridge, and Wagner reported dream-like experiences, possibly hypnagogic states. Watt also reported a dream-like mental imagery experience, but at an earlier point in his discovery not directly associated with the illumination. Hawking was getting into bed. Blanchard was driving home and Yellot was riding on a bus. Kekule also reported a mental imagery experience to have occurred while riding on a bus, but that experience was related to the incubation stage of his discovery and not the illumination. Watson was in his laboratory. Einstein and Snyder were both at work, though were not specifically working on their discoveries at the moment when the illumination was reported to have occurred.

For Watson, Chrysler, Thompson, Forshee, Wood, and Cray the application of mental imagery in the problem solving process was seemingly an intentional strategy they had chosen to pursue. The reports of Mendeleev, Hilprecht, Kekule, Hadamard, Tesla, Einstein, Yellot, Snyder, Blanchard, Bohr, Howe, Coleridge, and Wagner suggest that mental imagery was a spontaneous occurrence that was not intentionally directed. Watt reported to have intentionally directed mental imagery in one instance (part 1), but in the other report (part 2) he was asleep and the imagery occurred spontaneously in a (recurring) dream. Tesla reported the design for the AC generator to have occurred spontaneously, but elsewhere described mental imagery as a familiar and intentional aspect of his inventing process. Mozart reported to invent new compositions through an integration of spontaneously occurring mental images (auditory) that he proceeded to "methodize and define" by intentionally developing the composition as a mental image.

Feynman, Faraday, Galileo, Newton, Maxwell, and Poincare did not report the details regarding their illumination experiences and consequently it is unclear that mental imagery was involved specifically at that moment. Galileo, Newton, Maxwell, and Poincare's use of imagery in the expression of their ideas suggests that imagery may also have been involved in the illumination. Feynman and Faraday did not link mental imagery with particular discoveries, but Feynman Diagrams and Faraday's lines of force represent two of their most significant. Because visual-spatial forms of analysis are integral to their discoveries, it seems likely to suspect that imagery may have been a part of the illumination experience.

(Tartini and Berlioz each reported to have heard complete and original musical compositions in a dream. However, Tartini could not later reproduce the music to his satisfaction and settled for results that were admittedly his best, but far below the one he had heard in his dream. And Berlioz never recorded the music he heard so it is impossible the verify that an illumination had actually occurred.)

<u>Verification</u> (5;7+6). Evans, Watt, Tesla, Einstein, Yellot, Blanchard, and Galileo all reported complete confidence in their discoveries based on the mental images they had reportedly perceived and without the need for objective verification. The verification process, or some subjective equivalent to it was integrated into the reported imagery experience. Evans, Watt, Tesla, Yellot, and Blanchard invented designs for new machines. Einstein and Galileo made discoveries a physical law: gravitation.

In addition to those cited above, the reports about Nasmyth, Snyder, Watson, Blanchard, Faraday, and Galileo suggest that mental imagery may have provided some verification in their discoveries or inventions as well. Nasmyth, Snyder, and Blanchard invented designs for machines or mechanical processes. Watson, Faraday, and Galileo discovered physical properties: Faraday and Galileo about physics, and Watson about biological genetics.

(Mozart's report that the music "rarely differed on paper from what was in my imagination" suggests that he also believed it had been verified, though the verification for a work of art is based on different criteria than in the sciences.)

5.2 Distribution of results

Number of reported incidents:

Primary data	(15)
Secondary data	(29)
Combined	(44)

Number of individuals represented:

Primary data	(14)
Secondary data	(27)
Combined	(41)

Number of authors in the secondary data:

Subject's self report	(18)
Biographers or historians	(11)

1. Possible causes:

Walking	(3;3+1)
Riding in a bus or carriage	(2;3+1)
Sitting	(2;2+4)
Lying down	(2;3+9)
Hypnagogic experiences	(1;3+2)
Sleeping	(2;7+4)
Exhaustion	(2;3+0)
Getting into bed	(1;1+0)
Outdoors	(2;2+1)
At work	(3;3+0)

Intentionally developed skills	(2;3+0)
Hereditary/Genetic	(1;1+1)
One time experiences	(5;11+0)
Multiple experiences	(4;18+4)
Alone	(4;8+1)
Accompanied	(1;1+0)
Thinking about the problem	(2;2+3)
Not thinking about the problem	(6;7+4)
Consciously directed	(4;9+6)
Not consciously directed	(6;13+1)
Positive affective quality	(3;5+0)
Negative affective quality	(4;7+0)
Insomnia	(0;2+0)
Intoxication	(0;1+0)
Gazing fixedly	(0;0+2)
Pareidolia	(0;0+1)

Number of different factors indicated under possible causes:

Primary data	(22)
Secondary data	(16)
Combined	(24)

2. Perceptual modalities:

Visual	(13;37+0)
Tactile/Kinesthetic	(1;2+8)
Auditory	(1;5+3)
Verbal	(1;3+2)
Time condensation	(1;2+2)

3. The stage in the creative process at which imagery was reportedly involved:

First insight	(1;5+7)
Saturation	(3;10+2)

Incubation	(2;2+0)
Illumination	(11;22+6)
Verification	(5;7+6)

5.3 Conclusions

5.3.1 Possible causes.

Primary data:

There were twenty-two different factors reported in the primary data that may possibly have facilitated the perception of mental imagery. There were also sixteen reported in the secondary data, representing a combined total of twenty-four. There were two additional factors that were suggested, "gazing fixedly" and "pareidolia," but they were less clearly established than the others.

For the primary data, the distribution of reports according to the number of occurrences per factor ranged from one to six out of fifteen. Factors that were reported in only one incident are nevertheless considered significant because they each represent aspects of the human potential. There were two factors that each were reported in six cases and represent 40% of the total number of incidents in the primary data, and 43% of the individuals involved. Those factors were: not thinking about the problem at the time the reported imagery occurred, and not having consciously directed the reported imagery. These factors are closely related. Not thinking about the problem refers to the subjects conscious thoughts leading immediately up to the reported imagery experience, while not having consciously directed the imagery refers to the level of conscious control over the imagery. The results indicate that these two factors were the most significant causes for the reported perception of mental imagery in conjunction with creative problem solving in the sciences. There were three subjects who were represented in both factors, but between the two they comprise a total of nine different subjects, representing 60% of the incidents and 64% of the individuals in the primary data.

There was a corresponding balance in the results from the factors representing propositions that were the inverse of those that were the most significant. Thinking about the problem was described in two cases, and consciously directed imagery was described in four cases. One case occurred in both factors (Watt, part 1), making the combined total 5, and representing 33% of the cases and 36% of the individuals in the primary data.

Approximately two-thirds of the reported incidents in the primary data include references to not thinking about the problem when the imagery occurred or not consciously directing the imagery as it occurred. A corresponding one-third reported the inverse propositions and were thinking about the problem when the reported imagery occurred, or consciously directed the mental images as they occurred.

One time isolated mental imagery experiences were the third most significant factor after not thinking about the problem and not consciously directing. One time experiences were reported by five different people, representing 36% or slightly over one-third of the individuals in the primary data.

The most significant factors revealed by the results from the primary data were "not thinking" and "not directed" with six incidents of each, and "one time experience" with five. These results suggest that mental imagery in conjunction with scientific discovery can occur spontaneously, that it is often not subject to conscious control, and that they are frequently unique and isolated one time experiences. Unfortunately, there are no concrete strategies for the intentional development or facilitation of mental imagery suggested by these factors.

Following one time experiences (with five) are four different factors each described in four separate reports from the primary data. Multiple experiences, being alone, consciously directed imagery, and negative affective qualities each represent 27% of the incidents and 29% of the individuals, or nearly one-third of the primary data each. There is no obvious relationship among these factors, however they provide more concrete possibilities for the development of mental imagery experiences. The most obvious is being alone. Although there was an account from one person in the primary data who was accompanied (Tesla), almost one-third (29%) of the people were alone when the imagery reportedly occurred. An equal number, close to another one-third reportedly were able to consciously direct the reported imagery. Although it is not indicated as strongly as not consciously directing (with six), consciously directed imagery was reported by four out of fourteen subjects (29%) in the primary data. This finding indicate that mental imagery was equally effective as a problem solving technique regardless of the level of perceived control over the images.

The reports of multiple mental imagery experiences suggests that once the faculty has developed it is subject to recurrence. Certainly this is true for those scientists who described intentionally developing their mental imagery skills. These findings are at odds with the slightly more significant results about one time experiences. Except for those few who intentionally developed imagery skills or were naturally inclined toward visual thinking (Einstein, Feynman), the evidence from the primary data suggest that recurrent mental imagery experiences are unpredictable and perhaps infrequent. Nevertheless, the reports that certain people have succeeded in developing these skills suggests it is with the realm of human possibility. Galton (1883) and Sebeok (1993) have suggested this may be a hereditary/genetic phenomenon. Tesla reported that his brother suffered from a similar affliction regarding the appearance of tormenting images suggesting there may have been a hereditary component. However, Tesla was the only person in the primary data to make such a claim.

The reports of the perception of a negative affective quality in conjunction with mental imagery are not surprising considering the number of dream and dream-like, or hypnagogic experiences that are represented in the data. However, of the four people who reported to have experienced negative affective qualities, only Kekule's reverie was dream-like. Kekule's report was also the least emphatic description of negative affective qualities. The rest were reportedly fully conscious and awake at the time the reported imagery occurred. With the exception of Yellot was bothered by personal matters when the imagery reportedly occurred, there was no apparent cause for the negative affective states reported by the other three. Perhaps there is some connection between mental imagery processes and emotional responses.

There were three factors with three incidents each. Walking, at work, and positive affective qualities were each reported by one-fifth (21%) of the people. Although this is slightly less than that the report of negative affective qualities reported by 29%, the two factors are closely related and represent not divergent tendencies but perhaps different manifestations of the same tendency. While positive affective qualities may reflect the recognition of having made a significant discovery, as in Archimedes *Eureka!* parable, negative affective qualities may relate more closely to the struggle inherent in the creative problem solving process. These two factors that seem to express the same basic tendency to experience mental imagery in association with an emotional response. Their combined number of incidence equals seven, making it the single most significant tendency revealed, representing half (50%) of the individuals and almost one-half (47%) of the incidents in the primary data. There were no indications that the reported affective qualities were subject to intentional control, although Tesla did report to have developed alternate imagery strategies to cope with sudden appearance of tormenting images during childhood.

Three people reported they were at work when the mental imagery occurred, but of the three only Watson was specifically working on the problem when the imagery occurred. For Einstein, who was sitting in a chair, and Snyder, who was walking down the hall, there did not seem to be anything about the work environment that facilitated the solution to their problems since they were reportedly not thinking about the problem at the time. Perhaps the familiarity of the surroundings created a sense of comfort or reassurance.

Snyder is also represented in the group of three people, including Watt and Tesla who were walking at the time when their mental imagery experiences reportedly occurred. Perhaps there was something about the act of walking itself that facilitated a state of mind conducive to mental imagery and/or creative problem solving. Walking is often considered a way to release stress and anxiety. Any form of physical activity can be an effective way to release stress and anxiety. Perhaps walking provided a balance between helping to promote a relaxed state of mind and yet not requiring so much attention so that they were unable to concentrate (as with competitive sports).

Watt and Tesla were walking outdoors when their reported imagery occurred, perhaps indicating that a change in scenery had facilitated a change in thinking processes as well. This contradicts the familiarity theory about imagery occurring at work and suggests there is no expectable place for imagery to occur. The place where imagery seems most likely to occur is lying down, in bed or wherever they happened to be where they were able to relax: Two people were sleeping, two more were lying down, two were exhausted, one was getting into bed, and one reported a hypnagogic experience. In addition, there were nine other cases in the combined primary and secondary data where it was possible they were lying down at the time, though no specific details were provided. Hadamard, for example reported to have suddenly woken up. Furthermore, two people reported they were each riding on a bus, and two people were sitting down at the time when the imagery reportedly occurred. These factors, as well as walking may also have helped to promote a relaxed state of mind though they did not involve laying down or falling asleep.

Secondary data:

With the inclusion of the secondary data there were several significant developments in the results of the possible causes for the perception of mental imagery, the most dramatic of which was the rise in reports of multiple imagery experiences from four, representing 27% of the incidents in the primary data, to eighteen incidents in the combined primary and secondary data. Although there was a correspondent rise in the total number of incidents from the primary to the combined data which rose to forty-four, including forty-one different people, the eighteen reports of recurring imagery experiences represent 41% of the incidents and 44% of the people. This increase shows the most significant change in percentage for a single causal factor, representing a 14% difference, or slightly more than a 50% increase over the percentage in the primary data alone.

Ironically, one of the next most significant changes was in the factor of one time experiences, which rose from five to eleven. Although the five incidents represent 33% of the primary data, the eleven incidents in the combined total represent a relative decrease in percentage to one fourth (25%) as a result of increase in the number of combined incidents. Nevertheless, this adjusted number may represent a more accurate representation because of the increase in group size. Unlike the results in the primary data, multiple imagery experiences in the combined results were indicated more frequently than one time experiences. However, the relative frequency of one time versus multiple imagery experiences only serves to establish that both are possible, though sometimes unpredictable.

There was an interesting rise in the combined data for two pairs of inversely related propositions. One pair, consciously directed and not consciously directed imagery experiences showed a more dramatic change, rising from four to nine for consciously directed, and from six to thirteen for not consciously directed. Nevertheless, the increase in total group size lowers the percentage of the results in the combined data. Consciously directed imagery represents 27% of the results in the primary data, while only 20% in the combined data, though the number of incidence more than doubled. Not consciously directed imagery dropped from 40% in the primary data to 30% in the combined, though again the number of incidence more than doubled. Although the combined data describe a relative drop in the frequency of these factors, the larger group size may help to improve the accuracy of the findings. As with the results of these two factors in the primary data, they are both indicated as possible perceptions associated with mental imagery experiences. The results are not as high in the combined results, but they may be more accurate due to the larger group size.

Both positive and negative affective qualities showed an increase in the number of incidents, although the larger group size served to diminish the percentage dramatically. Positive affective quality rose from three in the primary data representing 20%, to five in the combined representing 11% of the reported incidents; and negative affective qualities dropped from four in the primary representing 27%, to seven in the combined representing 16%.

Although positive and negative affective qualities are inversely related propositions, they represent the same tendency to experience emotional responses in conjunction with mental imagery, as mentioned above. Considered together as a single tendency, these two factors reflect a relative decrease in percentage from 47% of the incidents in the primary data to 27% in the combined, even though the number of incidents rose from seven to twelve. Although these numbers reflect a substantial decrease in frequency, the larger group size provided 71% more incidents of this phenomenon, adding credibility to the results.

The incidence of sleeping in the combined data rose from two in the primary data to seven, with a corresponding percentage increase from 13% to 16%, a relatively small increase in percentage but nevertheless a 350% increase over the results from the primary data alone. The combined data representing a significantly larger group size helps to validate the findings. The close match between the frequency results of sleeping in the primary data and the combined data helps to verify the accuracy of those results.

There were small increases in several other areas, but the increase in group size served to greatly diminish the significance of these findings. Riding in a bus or carriage, lying down, exhaustion, intentionally developed skill, and not thinking about the problem each rose from two incidents to three with the combined results, representing a drop from a frequency of 13% to 7% (although the number of reports involving sleep rose by 50%). The incidence of hypnagogic experiences rose from one to three, a 300% increase in number of occurrences but representing almost exactly the same frequency (7%) in both the primary and combined data.

With the exception of cases where no reference to the circumstances surrounding the moment of discovery were provided, in almost every case there were reports of everyday behaviors involved, such as walking, sitting, riding, being alone, exhausted, lying down, and of course sleeping, all of which tend to promote relaxation as well as perhaps a distracted state of awareness. This correlation between commonplace behaviors and mental imagery in creative discovery suggests that a certain degree of <u>indirect</u> attention is actually necessary in creative problem solving, especially in the later stages perhaps (see stage in the creative process below). These result should not surprise anyone who has experienced the frustration of not being able to remember some bit of information through the direct approach; however, it was not an anticipated result of this study.

In many cases the moment of discovery was reported to arrive in its final stage in an entirely effortless manner, without the least bit of struggle or even conscious direction. The causes for this phenomenon were not revealed by this study and remain unclear, but perhaps it is related to the state of relaxation or indirect attention facilitated by the commonplace behaviors cited above.

Several writers have echoed these reports about the role of the unconscious in the creative process. Researchers over the years have suggested several different but related theories to account for this elusive nature of creativity. These theories include: the antechamber of consciousness (Galton, 1883); fringe consciousness (Wallas, 1926); unconscious (Montmasson, 1932); preconscious (Kubie, 1959); chance (Taton, 1962); bisociation (Koestler, 1964); vestibule of consciousness (Coleridge; see Lowes, 1964); lateral thinking (De Bono, 1970); Janusian thinking (Rothenberg, 1979).

Ribot wrote, "It is the unconscious which produces what is vulgarly called inspiration" (from Myers, 1920, p. 58).

Coleridge (see secondary data above) poetically captured this experience:

> Ideas and images exist in the twilight realms of consciousness, that shadowy half-being, that state of nascent existence in the twilight of imagination and just on the vestibule of consciousness (Gerard, 1946; from Ghiselin, 1952, p. 228).

Although the role of the unconscious, like mental imagery is often more closely associated with creativity in the arts than in the sciences, several scientists and mathematicians have attested to its significance as well. Kekule wrote, "Let us learn to dream . . ." (Findlay, 1948, p. 38, see primary data).

Tyndall wrote, "With accurate experiment and observation to work upon, imagination becomes the architect of physical theory" (from Beveridge, 1961, p. 72).

Bertrand Russell wrote:

> In all creative work that I have done, what has come first is a problem, a puzzle involving discomfort. Then comes the concentrated voluntary application entailing great effort. After this, a period without conscious thought, and finally a solution bringing with it the complete plan of a book. This last stage is usually sudden and seems to be the important moment for subsequent achievement (from Hutchinson, 1949, pp. 19-20).

Russell's statement suggests that the illumination and perhaps the incubation were both carried out through unconscious processes.

Brewster Ghiselin, author of *The Creative Process* (1952) carried the argument so far as to write that, "Production by a process of purely conscious calculation seems never to occur" (1952, p. 8; see Rugg, 1963, p. 7).

Poincare (see secondary data above) was far more exacting in his approach to characterizing the role of the unconscious.

> The role of the unconscious in mathematical invention appears to me incontestable . . . (however,) it is possible and of certain it is only fruitful, if it is on the one hand preceded and on the other hand followed by a period of conscious work (Poincare, 1913; in Montmasson, 1932, p. 80; Hadamard, 1945, p. 14; Ghiselin, 1952, p. 38; cf. May, 1975, p. 65).

Poincare continued by describing the specific functions performed by both conscious and unconscious processes.

> What is the role of preliminary conscious work? It is evidently to mobilize certain of these atoms, to unhook them

from the wall and put them in swing. We think we have done no good, because we have moved these elements a thousand different ways in seeking to assemble them, and have found no satisfactory aggregate. But, after this shaking up imposed upon them by our will, these atoms do not return to their primitive rest. They freely continue to dance (Poincare, 1913, pp. 393-94; in Montmasson, 1932, p. 81; Ghiselin, 1952, p. 41; Simonton, 1988, p. 31; cf. May, 1975, pp. 67-8).

Poincare speculated that it was the conditions of civilized life that impeded the creative process (however this fails to explain why no tribal cultures have developed higher mathematics). Poincare wrote:

> In the waking moments of our complex civilized life we are ever in a state of suspense which makes all great conclusions impossible; the multiplicity of the facts of life, always present to consciousness, restrains the free play of logic (except for that happy dreamer, the mathematician). In our dreams the fetters of civilization are loosened (Ellis, 1915, p. 279).

Poincare's account is echoed by Einstein, who wrote that "All our thinking is of this nature of the free play of concepts" (Holton, 1978a; from French, 1979, p. 157; see Holton, 1979b; see primary data).

Arthur Koestler, author of *The Act of Creation* (1964) considered conscious thought itself to be an impediment to creativity. Koestler wrote:

> (The) temporary relinquishing of conscious controls liberates the mind from certain constraints which are necessary to maintain the disciplined routine of thoughts but may become an impediment to the creative leap; at the same time other types of ideation on more primitive levels of mental organization are brought into activity (Koestler, 1964, p. 169; see Budzynski, 1976, p. 363).

If Koestler associates unconscious processes with the process to facilitate creative leaps, which presumably represent our greatest accomplishments, then it is unclear why he would refer to them as more primitive levels of mental organization. Nevertheless, his description is exemplified in several reports included here.

Magoun characterized several of the reports involving spontaneous and undirected mental images by writing that:

> (Vigilant) attention may impede the free-flowing retrieval of previously stored material leading to innovative associations. The most significantly productive of creative ideas, relating disparate information and providing a new insight or synthesis, have often been reported to be generated not in the intensity of strained focused concentration upon the subject or problem, but rather during a contrasting state of mind, as when performing a stereotyped activity, or gazing hypnotically into a glowing fireplace, or even during sleep itself, in dreams (from Budzynski, 1976, p. 363).

These theories have been provocatively demonstrated by several reports presented here. Furthermore, the results indicate that mental imagery occurred most frequently while not thinking about the problem or not consciously directing the imagery. In several cases the subjects reported they were consciously thinking about the problem when the imagery occurred, or that they had consciously directed the reported imagery, but that does not exclude the possibility that unconscious processes were involved, possibly at some point in the creative process not connected with the reported mental imagery.

5.3.2 Perceptual modalities

The visual, auditory, and tactile/kinesthetic modalities were all represented in both the primary and the secondary data; however, the auditory and tactile/kinesthetic modes were clearly evidenced by only one incident each in the primary data. This is in contrast to the visual modality which was clearly described in thirteen cases in the primary data, representing 87% of the incidents and 93% of the individuals, as well as 81% of the incidents in the combined data. In the primary data, only Einstein did not clearly describe imagery in the visual mode, which is ironic because both reports about Einstein in the secondary data clearly describe visual imagery, and he himself stressed the primacy of visual thinking in his own thought process.

Howard Gardner, best known for his theory of multiple intelligences, suggests that this tendency toward the primacy of the visual modality may have a biological factor. Gardner wrote:

> My own view is that each form of intelligence has a natural life course; while logical-mathematical thought proves fragile later in life, across all individuals, and bodily-kinesthetic intelligence is also at risk, at least certain aspects of visual and spatial knowledge prove robust, especially in individuals who have practiced them regularly throughout their lives. There is a sense of the whole, a "gestalt" sensitivity, which is central in spatial intelligence, and which seems to be a reward for aging--a continuing or perhaps even an enhanced capacity to appreciate the whole, to discern patterns even when certain details or fine points may be lost. Perhaps wisdom draws on this sensitivity to patterns, forms, and whole (Gardner, 1983, p. 204; see West, 1991, p. 39).

Another reason visual imagery may have been reported most frequently is the nature of the problems themselves. Most of the reports cited in the data involve discoveries in physics and mechanical engineering inventions, both of which are inherently visually oriented disciplines. The implication is that mental imagery occurs most frequently in those areas that are best adapted to imagistic translation. This is evidenced both by those examples corresponding to visual imagery, as well as to the composers who all reported auditory imagery, sometimes in addition to visual (and even verbal perhaps).

There were also two additional factors found that are categorized under perceptual modalities because they are more closely related to specialized modes of perception than to causes for the perception of imagery. These are verbal communication and time condensation, each with one report in the primary data. With the inclusion of the secondary data, verbal communication raises to three, and time condensation raises to two, but there is little significance to these numbers except to establish the possibility that these type of experiences have occurred.

With the combined results, tactile/kinesthetic rose from one to two, again representing a small drop in frequency that is perhaps insignificant with such low numbers of incidence. Auditory rose from one to five, representing a jump from 7% to 11%. Both of these findings were still however dwarfed by the reports of mental imagery in the visual modality, which more that doubled from thirteen to thirty-seven incidents, and representing a slight relative drop in frequency from 87% in the primary data to 84% in the combined. The preponderance of mental imagery experiences in creative problem solving may indeed occur in the visual modality, but there may simply be a lack of documentation to describe the occurrence of such non-visual modalities. Perhaps this is the result not so much of the rarity of these experiences but of the difficult with describing them through language, in comparison with the relative ability the describe visual imagery in linguistic terms (see describing mental images in chapter 2 above).

5.3.3 Stages in the creative problem solving process

There were incidents in the primary data to represent every stage in the creative process (as defined under stages in the creative process in chapter 3 above). The most significant of these results was illumination experiences which were reported in eleven cases representing 73% of the incidents in the primary data. With the combined results the number doubled to twenty-two, with a corresponding drop to 50% of the cases reported but still representing the greatest number of reports for any of the stages. Verification was reported in five incidents in the primary data (33%), and seven in the combined (16%). Saturation was reported in three incidents from the primary data (20%), and ten from the combined (23%). First insight was reported in only one incident in the primary data (7%), but five in the combined (11%). And incubation was reported in two incidents in the primary data (13%).

Apart from simply establishing that each of these stages has been described in association with mental imagery, the results suggest that mental imagery has been perceived most frequently in conjunction with the illumination stage (the moment of discovery). The illuminating experience was reportedly carried in a mental image in almost three-quarters (73%) of the primary data and exactly one-half of the combined number (50%). These numbers may be misleading, however, because the primary data represent only those mental imagery experiences that culminated in creative productions (discoveries or inventions), indicating that an illumination experience had occurred.

In the primary data, verification was the second most frequent with five reports or 33% of the data. Verification connotes objective verification, however, these reports represent entirely subjective experiences. The incidents where I have proposed that a verification experience occurred do not represent the verification of solutions in the traditional sense, but to the subjects themselves, their reported imagery experiences also provided sufficient verification. The content of the reported imagery did prove to be accurate, and in certain cases the objective consideration of the images themselves provides conclusive evidence for the theory, such as Einstein's example of the falling person not being able to feel the weight of their own body, or Galileo's argument about the rate at which objects of different weight will fall (see also Maxwell and Poincare). Because works of art are subject to a different sort of verification from scientific discoveries or inventions, they were not calculated into these results, even though there were reports of completed compositions occurring through mental imagery (see Mozart, Wagner; also Tartini and Berlioz).

By combining the results from the secondary data, verification raises slightly to seven (with a corresponding drop in percentage to 16%). Saturation rose from third place in the primary data with three (20%), to second place in the combined primary and secondary data with ten (23%). The consistency between the frequency of saturation between the primary and combined results is notable considering the analyses are subject to innumerable vagaries between the reports.

First insight was reported in only one incident in the primary data (7%), but by a total of five in the combined results (11%). Incubation was reported in two incidents (13%) in the primary data with no additional reports in the secondary (and a correspondent drop in the combined results to below 5%).

Presumably mental imagery may have occurred in association with the preliminary stages in the creative process, like saturation or incubation, yet perhaps not contributing directly to any specific results (illuminations). Several scientists and inventors reported that mental imagery, especially visual, functioned as the crucial mode of operation in the early stages of their creative process without specifying the direct results, however expressing proven confidence in the success of this method (see Dodge, Thompson, Forshee, Wood; see also Einstein, Feynman, Faraday, and Poincare).

Not surprisingly, comparison of the reports suggests they were not written following a uniform conception of the stages in the creative process; indeed, creativity may not be a uniform process. The conception of creativity as a five step process was used in order to help determine the points at which mental imagery has been reported with the most frequency. Although the stage theory can be useful, many of the reports resisted the interpretations imposed by that conception. These differences may be purely semantic, but may also suggest that the stage theory represents an insufficient model of the way discoveries are made.

A final feature of moments of discovery is that many were reported to arrive in an all at once way, whereby the completed solution to the problem arrives seemingly instantaneously. It has been well documented that the perception of time seems to stand still during moments of creative behavior (Csikszentmihalyi, 1991). This is one possible explanation, but there is also the possibility that moments of discovery sometimes do occur in an instantaneous way. Some reports included here suggest that the discoveries occurred seemingly instantaneously; others indicate that they transpired over remarkably short periods of time, possibly occupying the span of a few minutes or an hour. The results of this study offer no conclusive explanation for this phenomenon, however, the results suggest that mental images are capable of carrying substantial amounts of information over highly attenuated time intervals (see time condensation).

5.3 Summary

Fifteen reported incidents were found to meet the standards of the primary data, and forty-four for the combined primary and secondary. The single most frequently reported factor was imagery that occurred in the visual modality, though imagery in the auditory and tactile/kinesthetic modalities were also reported. The frequency of reported imagery experiences in the visual mode may reflect the types of investigations represented. Physics and mechanical engineering both tend to rely on pictures (diagrams), suggesting that relevant imagery was more likely to have been perceived in the visual mode. All four composers included in the secondary data reported to have perceived auditory (musical) imagery.

There were twenty-two different factors found that may have contributed to the imagery experiences reported in the primary data, and twenty-four in the combined results. The individual factors measured relatively low frequencies, however, several factors seem to indicate a similar trend toward a range of activities involving common everyday behaviors. Results of this study indicate that mental images occurred more often in a spontaneous, unexpected way while the subjects were relaxing or otherwise preoccupied with routine behaviors. Specific behaviors include walking, sitting, riding in a bus or carriage, lying down, and sleeping. These behaviors may have provided a certain degree of distraction perhaps, but were not so demanding that they required complete and undivided attention. Not thinking about the problem when the solution occurred, and not consciously directing the imagery were two of the most frequent factors; they may also be related to the same trend.

The results suggest that mental imagery more often occurs in conjunction with routine behaviors while the subject may not be aware that they were thinking about a specific problem at the time. This study suggests that mental imagery is often the result of indirect causes, though a few people reported to have perceived them at will. The data suggest that mental imagery has occurred across the range of stages in the creative process, but mental imagery was reported to occur more frequently during the later stages (illumination, verification). Several imagery experiences were reportedly accompanied by affective qualities; in some instances the affective qualities were perceived as positive, in others they were perceived as negative.

Mental imagery has been reported in conjunction with a range of creative behaviors from fiction to physics. Although mental imagery is more often associated with fiction, this study helps to establish the significance of mental imagery within the scope of scientific reasoning. One of the remarkable aspects of mental imagery is its application to scientific observation and experimentation. In several cases scientifically verifiable results have been reported from experiments conducted exclusively within an individual's mind.

Dream-like imagery such as sleeping dreams and hypnagogic experiences were reported with surprising frequency in conjunction with scientific discoveries, confirming the theories of several writers that conscious thought processes are sometimes an impediment to creativity, not only in the arts but in the sciences as well.

Though there were cases where mental imagery skills were reportedly developed through practice and exercise, these reports were rare, reportedly occurring in only two cases in the primary data, and a total of three in the combined. In cases where mental imagery was not a customary part of the thinking process, it was reported to occur more often by not thinking about the problem than by thinking about it. As Kekule wrote, "Let us learn to dream . . ."

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