To again feel the creative voice

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Abstract

Science and mathematics education needs to serve several (possibly contradictory) motivating goals. One is found in the movement for a universal literacy in the central principles and methods of the disciplines. The second is the need to provide the experiences and background that makes possible the production of scientists and engineers. A complication in both efforts is that the formal education takes place over many years, and the application of the layers of information, understanding, and sophistication need also be aware of the age of the student and what has come before. These efforts require clear ideas as to the end goal of the process and attention to assessment. Receiving less attention is the need to also feed and nurture the creative side of those who would become professionals, as creative approaches will be a central and necessary aspect of their work and thought.

In this paper, I address the use of a course in Mathematical Modeling taught over a period of 25 years to undergraduate students of Mathematics, Mathematics Education, Computer Science, and Engineering, as a method to open up creative pathways. Through an historical discussion of the role and nature of creativity in the sciences and mathematics, a process to have students find their creative voice is described in the context of this course.

Introduction

Hodson (1992) identified three purposes for science education, summarized as learning the ideas, learning the culture (history and methodology), and learning how to do science. The same three apply to mathematics. The easiest aspects of the three purposes, both for teaching and assessable learning, are the first two. The third, however, is what professionals would call science – and similar examples can be found in any discipline. In writing, for instance, one can learn the techniques of writing, literary criticism, and study great writers, but one is not a writer until one writes. Central to doing science or mathematics is the construction of conjectures, examples, and preliminary work that enable one to pose a testable hypothesis. The process by which one then takes these bits of observations and germs of ideas and produces hypotheses is at its nature a creative one.

In this paper, after a general historical discussion of the creative process as seen in science and mathematics, the creative process as seen in 25 years of teaching a course on Computational Models is described. In this course, evidence of the creative process is demonstrated by the solving of a "hard problem," that is one that cannot be solved by direct means in a short time. The potential for using modeling in this way, as the basis for teaching creativity in science and technology education, has been explored by Davies & Gilbert (2003). Their work identified the potential, but there are few experiments to test this idea at this time.

This paper has another purpose as well. It is written to encourage each reader to reflect on his or her own use of the creative process. It is the recognition of the reader's own process that reveals what should be taught to our students. Teaching the process can only be done through having the students experience the creative voice in a personal way, having a teacher understand and describe their process would be a good start. The methods by which this is done will necessarily differ greatly with the setting. Having them play is the beginning.

The Creative Process in Children

When one is young, a common fantasy is that of the super hero. You put on a cape and mask, maybe take off your glasses, and become the one who fights for the weak, the poor, and the oppressed. Earthly limitations are not barriers. You can fly, compel suspects to tell the truth, and display extraordinary strength, intelligence, and bravery. During these moments of immortality, you have no sense of time, and your imaginary world is tangible and tangible objects become mysterious and magical. Playmates in this state are integral parts of this magical world. They see you as magical and mythical as well. For a child it is easy to join that world. All kids can do it. But, it seems inevitable that your responsible adults eventually pull you back from that state of mind, remind you of the time, and tell you to come back to Earth, to take off your cape and mask, to stop daydreaming, and to "grow up." Without your cape, you become bound by earthly laws and subject to the common cold and diarrhea – you join the "real" world[1]. This period of childhood is essential to development. Young humans who have had to grow up too soon without the experiencing childhood may be at risk (Goleman (1997); Crain (2004)). Moreover, free play and direct experience of the mysterious form a basis for creative responses to life.

> *In the creative perceptions of poet and child we are close to the biology of thought itself – close, in fact, to the ecology of imagination, in which the energies of the body and mind as a unit, an ecosystem, and the energies of nature combine in a mutual endeavor to adapt to nature, to culture and to the societies devised by man to embody culture.*
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> *Edith Cobb (1895-1977)*
> *The Ecology of Imagination in Childhood, 1977*

If it is the case, as Cobb states, that the imagination and ways of thinking of the child are at the core of creative approaches to the world, it would seem that this playfulness would be nurtured throughout formal schooling as something essential to preserve. To the contrary, Boostrom (2005) notes that the nature of modern education has been defined as the classroom. Although subjects in our liberal education model was based on that of the Greeks, who used few formal classrooms, the style of instruction has become more defined by what happens in the classroom and the disciplines defined less by ordinary life and life experiences, and more by "abstract mental endeavors." (Boostrom, 2005, p.52). The side-effect of seeing life-experience and emotional responses to that world as external to the educational process are many fold. One is clearly that students find the curriculum as external to their life (Boostrom, 2005). As a result, great discipline is required for the student is to master these subjects. A second effect is the disconnection of the creative from the curriculum.

In addition, education acts to suppress the creative expressions that do appear. In fact, today's characteristics of a "good school" coincide quite strikingly with the general killers of the natural urge and rewards to create as identified by Amabile (1996): surveillance (hovering over), evaluation, excessive rewards, competition, over-control (narrow specifications), restricting choices (instead of allowing the following of curiosity), and the pressure of expectations. Sounds like a traditional school getting students ready for standardized testing. The importance of the arts in preserving creativity is discussed in Rogers (2001) and Bjorkvøld (1992). In these works, the approach to teaching children in art and music rely on preserving the child-like creative energy. Bjorkvøld makes a strong case for the inconsistency of the structures of organized schooling for preserving contact with the "muse-ical."

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[1] Real has its root in the Latin for the legal relationship to things – as in real estate.

It is not just the playfulness of the child that is essential to maintaining creative expression inscience, as that does not address the central role of curiosity in scientific endeavor. Many statements of scientists and mathematicians throughout the ages give testimony to the role of mystery and wonder (often expressed as a contact with nature) as a source of their scientific curiosity.

> *The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead: his eyes are closed.*
>
> *Albert Einstein (1879-1955)*
> *from "Mein Weltbild" (1931)*

Einstein also notes the commonness in the creative experience for both art and science. This is another theme that runs through many testimonies – the commonness of the experience of the creative regardless of discipline. For us, it opens up another source of information as to how the creative can be encouraged in our students.

The nature of creativity, imagination, and intuition has been studied and described for several thousand years. Periodically in the past 100 years there have been rebirths of the examination of the nature and characteristics of creative people, collections of essays by creative people in various fields, and proposals for education of the young to encourage creativity. Fox (2002) and others have, also examined seeing creativity and imagination as gifts of the gods, as the Greeks saw the muses.

> *I decided that it was not wisdom that enabled [poets] to write their poetry, but a kind of instinct or inspiration, such as you find in seers and prophets who deliver all their sublime messages without knowing in the least what they mean.*
>
> *Socrates (469 BCE-399 BCE)*
> *In Apology, sct. 21, by Plato.*

Here I will propose a path to regain one's creative voice, using a course in mathematical modeling to illustrate the steps. The goal is to reopen the well of inspiration capped by the shroud of schooling. The process traditionally begins with an invitation:

"O Muse, Precious one, sing to me,
Thy inspiration a prelude for my own song
Send a breeze from your groves
Inspire my heart and mind
O Wise Kalliopeia
Leader of the golden Muses
And you too, wise initiator into the mysteries,
Apollo, Son of Leto,
Be at hand, blessing me."

--Mesomedes of Crete, 2nd c. C.E.
"Hymn to the Muses"

The Creative Process and the Creative Voice

It is important to define the nature of creativity to be discussed here. The word is loosely used and has many connotations. By creative voice I mean the inspiration coming to a single person usually in response to some expressed need. It does not mean being creative in a committee or creatively getting along with colleagues. Piirto (2004), Goleman et al. (1992); and Gryskiewicz and Hills (1992) discuss creativity in its many forms and provide suggestions for the increasing creativity in children, adults, and in business situations. Whether creativity of that type can be taught and learned in educational settings has been a productive research question. A good bibliography of the evaluation of the teaching of creativity can be found at http://www.creativelearning.com/CPSBiblio.htm.

Experiencing the creative voice is generally described and understood as a uniquely solitary event. Creative individuals describe the voice as coming from the muses, a daemon, God, an oracle, higher beings, or the unknown guest. They tend not to describe the experience of this voice as coming from within (as the experience is seen as beyond the conscious). The creative artists or scientists who benefit from this creative voice often attribute authorship to the "Muse." In my case, in some of my writing I have no recollection of the writing itself, and when I read it later, I do not recognize my hand. The source of that work is not my conscious mind, although the writing itself required some participation of the conscious mind through deep concentration. The writer Julia Cameron describes that process as follows.

> *I learned to get out of the way and let that creative force work through me. I learned to show up at the page and write down what I heard. Writing became more like eavesdropping and less like inventing a nuclear bomb. … I didn't need to be in the mood. I didn't have to take my emotional temperature to see if inspiration was pending. I simply wrote. No negotiations. Good, bad? None of my business.* ***I*** *wasn't doing it. By resigning the self-conscious author, I wrote freely.*
>
> *Julia Cameron*
> *The Artist's Way, 1992*

What is to be discussed here is not "flow" (Csikszentmihalyi, 1990 ; Csikszentmihalyi and Csikszentmihalyi, 1988). In that state, a person is unaware of time resulting from a deep concentration, losing the awareness of self. This "mindlessness" enables the individual to accomplish a task without the intruding distraction of consciousness. This condition is common in athletes (in the "zone" or "on fire") and with mathematicians where deep concentration is required due to the nature of the work. The feeling of flow is pleasant, and one wants to go there after experiencing it. You feel alive. The activity is not always creative or imaginative in the sense described above. With the creative voice, you feel driven by the voice. The experience is not always a pleasant one, and as we shall see, hearing the voice is often the result of anxiety and deep preparation (during which one may have been experiencing flow). The role of flow during a creative event is discussed in Csikszentmihalyi (1996). A good way to think about this distinction is the creative voice often appears in response to a need and the resulting internal stress and anxiety. Flow can be experienced without this stress. The role of stress may actually be to open us a path to the "muse" as noted by poet Stevie Smith.

Why does my Muse only speak when she is unhappy?

She does not, I only listen when I am unhappy
When I am happy I live and despise writing
For my Muse this cannot but be dispiriting.

Stevie Smith (1902–1971), British poet, novelist.
"My Muse" in Selected Poems (1964).

We have an easier time recognizing a creative act than defining creativity – we know it when we see it. The act of creation brings into being (into the real world) that which was not previously present in that world. It is not a reworking of existing materials in a "creative" way. In some discussions, creative as being discussed here is written with a big "C." In an effort to describe the creative process by testimonies of how these ideas came into being (that is, into our conscious minds and the real world), several interesting accounts, many first hand, have been collected, for instance Harding (1948); Ghiselin (1952); Inglis (1987); Barron et al. (1997); and Barrett (2001). The common threads in these accounts from artists, playwrights, poets, writers, musicians, scientists, inventors, and mathematicians illustrate the experience of the creative voice. The commonality of the experience is striking. The experience and importance in the sciences is not unlike that in the arts.

A different approach to studying creativity is to define characteristics and abilities common to creative people (Piirto, 2004; Root-Bernstein and Root-Bernstein, 1999) as a basis for educational programs. The thought in these works is that if we foster the tools used by those who have created, there will be more people creating. Fostering the habits of creative people in those who are not creating is the basis for "creativity training." This approach does not address the curiosity and drive present in the creative. It also assumes that if all the techniques are in place, insight and inspiration will follow. This approach should be seen as part of the preparation process discussed below.

Creativity has been described as our true nature as humans and gifts from God (Fox, 2002). In this view, the soul is often seen as the seat of creativity and imagination. In the Christian view, the Holy Spirit brings the creative force to mankind and creativity is an act of a human and the divine in communion. In this sense, a creative act requires the surrender to the river of creativity flowing through all of creation. Creating becomes an act of praise and thanksgiving. This idea may have come from the Greeks through the myths of the creation of the muses as related in Pindar's hymn.

Zeus had brought the world into being, and the gods beheld in mute wonder the magnificence that lay before them. But, Zeus asked, is not something wanting? And the gods replied that yes, one thing was wanting: the world lacked a voice whereby all this wonder could be expressed in words and music. In order for such a voice to sound there was a need for a new kind of divine beings – whereupon the Muses sprang into existence as the children of Zeus and Mnemosyne, goddess of memory.

Pindar (518-438 BCE)
"Hymn to Zeus"

Creative thoughts generally do not result from the emptying of the mind present in deep meditation. The silence of the voice seems to be due to the role of stress in the process. May (1994) identifies creative people as those who can live with (periodic) anxiety and the resulting difficulties in exchange for the gift of the "divine madness."

When I am engaged in writing something important to me, I find that if I engage in the customary twenty-minute meditation period before writing, my universe has become too straightened out, too orderly. Then I have nothing to write about. My encounter [with the

problem] has vanished into thin air. My "problems" are all solved. I feel bliss, to be sure; but I cannot write.

Rollo May
The Courage to Create, 1994

There is a clear division in the nature of published work on creativity. They can be categorized as to whether the word "dream" appears in the index. In general, those without "dream" approach creativity as a discipline of the conscious mind. This characterizes much of the work in organizations and businesses where mastering the social dynamic is essential (the real world). Most works *with* "dream," on the other hand, argue that every big act of creation requires a dream-like state. For them, it would seem that creative people are those who have contact with their creative voice and have developed the technique necessary to express the message in some way. This second idea is supported by the first hand reports of people who create. They find that the reason that few individuals are able to express the creative voice is seen by the need both to prepare and to learn to listen, remember, and interpret the message. There must be deep preparation in the medium in which the message is to be expressed. Those that are to write must learn the rules of writing and write, and painters must learn technique and paint. This is because the result of creation is something that must be brought into the real world. Spelling and sentence structure are important in order that the tangible response to the voice can be brought to the real world and communicated to others.

Steps of the Creative Process

There are identifiable steps in the creative process. Both conscious and unconscious processes are involved. The steps are not always taken in order and one tends not to know where you are in the process until it is completed. Nonetheless, it is useful to give some structure to this discussion by describing them. As proposed by Wallas (1926) (see also Murphy, 1958) the steps of the creative process are

a) Preparation
b) Incubation
c) Illumination
d) Verification.

Preparation involves both mastery of the discipline and practice in identifying and hearing the creative voice. This involves relating dreams, creating a habit and a "sacred space" for the work, being open to stimulation from the other arts and people, and time for the process.

Incubation involves immersion in the problem, more time, and the invocation of the muse. This is a stage when the issue to be addressed is clearly put front-and-center in the mind and thus a "dream" or insight is requested.

Illumination comes when an answer is found in the unconscious and presented and recognized by the conscious (often instantaneously). Newton described the process of incubation and illumination very clearly.

I keep the subject of my inquiry constantly before me, and wait till the first dawning opens gradually, by little and little, into a full and clear light

Isaac Newton (1642-1727)

Verification is the necessary step to insure that the solution provided is valid in the real world. The mathematician Hadamard (1945) describes this phase as one where one must verify and "precise" them. In verification, the absolute feeling that the inspiration must be true might be deceiving us. Poincaré (1915) notes that this sometimes happens when ideas come during hypnagogic states (upon waking or falling asleep). "Precising" an idea means to state the illumination completely, fill in the blanks, and flesh out the insight. Verification can also be seen in a report or paper that relates the work to others.

It is the premise of this paper that hearing the creative voice and being able to translate the message into tangible conscious product (incubation and illumination) sit at the core of a successful creative process, and both are made possible by preparation. These aspects separate the technician from the creative. This aspect of the work is described by Ulam.

> *I am pretty sure this "habit" of originality exists in mathematical research, and I can point to those that have it. … What people think of as inspiration or illumination is really the result of much subconscious work and association through channels of the brain of which one is not aware at all.*
>
> *S.M. Ulam (1909-1984)*
> *Adventures of a Mathematician, 1976*

The first three steps of the creative process are the most important and will be discussed in detail.

Preparation

Preparation for creation is in three parts:

1) preparation in the discipline of the art
2) preparation in the discipline (habit) of listening to the voice
3) preparation through immersion into the problem

The creative voice speaks to those who have prepared themselves. The tools to implement any insight received are those experiences, techniques, and abilities developed up to that time. And, developed to an extent that they are automatic – not needing conscious intervention. This means that there are no shortcuts to being creative. One must practice the musical scales, draw the urns, and complete the mathematical exercises. The eventual goal, however, is the development of technique, not the completion of problems 10-15. I am often asked in teaching mathematics, "what good is this stuff I will never use?" In this context, the answer is not, "trust me, this algebraic manipulation comes up repeatedly when you grow up," but "the goal of this is to be able to do it without [conscious] thought." To have a creative event, one must have both the inspiration and the ability and experience to execute it. Developing technique as an artist, writer, or scientist is necessary. Nachmanovitch, a improvisational musician, states it best.

> *To create, we need both technique and the freedom from technique. To this end we practice until our skills become unconscious. If you had to think consciously about the steps involved in riding a bicycle, you'd fall off at once. Part of the alchemy engendered by practice is a kind of cross-trading between conscious and unconscious. Technical how-to information of deliberate and rational kind drops through long repetition from consciousness so that we can "do it in our sleep."… When the skill hides itself in the unconscious, it reveals the*

> *unconscious. Technique is the vehicle for surfacing normally unconscious material from the dream world and the myth world to where they become visible, nameable, singable.*
>
> *Stephen Nachmanovitch, musician*
> In Free Play, 1990

Preparation also involves development of the tools recognized in creative individuals as described in Root-Bernstein & Root-Bernstein (1999). The authors identify 13 tools necessary to "school the imagination": observing, imaging, abstracting, recognizing patterns, forming patterns, analogizing, "body thinking," empathizing, dimensional thinking, modeling, playing, transforming, and synthesizing. These tools provide a familiar vocabulary for the creative voice and a practiced road to consciousness. They also provide bridges between the unconscious and the real world to aid in the application of the insight to the problem at hand. In terms of preparation, several of these tools help to define the problem in vocabularies more familiar to the unconscious – more geometric and less analytic in the terms used by Poincaré (1915).

Preparation in the habit of listening to the voice involves a regular, almost ritualized, process of showing up with the pen and paper, paints, sitting at the piano, or at the computer. Part of the importance of the importance of "showing up" is that ideas, solutions, and insight often arrive irregularly. One must regularly invite the insight and be ready for its coming. Sometimes there is no voice and the time is spent cleaning brushes (another repetitive process). Practice in listening is also necessary to recognize the form that the creative voice takes in your life. The voice can be recognized as a vision, original music in your head, sudden clarity, whispers, or in symbolic forms. Without the recognition of the form(s) the voice takes with you, it is common to not recognize the gift when it comes. The ritualized nature of the practice also helps one get into the frame of mind (-lessness) necessary. I find that identifying four-hour blocks of time that will be set aside during a week is important. It takes an hour or more of familiarizing oneself with the material, an hour or so of productive work, some cool down time, then a nap is very productive. The nap plays an important role as shall be seen later.

The necessity to become immersed in the problem seems to play two roles. One is to define the issue that makes the insight necessary – to define the problem. By working diligently on the problem, and surrounding oneself with all aspects of the problem, one hopes that the clues necessary to the solution have been uncovered and examined. Some problems (the "easy ones") yield to this direct "work hard" approach and as one gains in experience more problems fall into this category. But the nature of the work and its difficulty can present roadblocks to the direct approach – as can the stubbornness of the investigator and perceived real world limits. In many cases, the goal of immersion is to define the real world contradiction present in the problem that makes a direct approach difficult. This is a primary idea of TRIZ (Russian "Theory of Inventive Problem Solving") in business contexts and similar approaches. The second role is that immersion also makes the unconscious more apt to work on the problem in dreams and in the background during consciousness, the aspect of the problem solving process called incubation. An aspect of the immersion is that the personal importance to solving the problem (or better said, the psychic cost in not solving the problem) is made tangible. "I must finish this." "There must be a way." "My career depends on finding the design." These are all phrases that once uttered or thought, inform the unconscious that this issue requires the highest priority. The creative voice speaks in response to a need, stress, frustration, or anxiety. One also must have the desire or curiosity to get past the frustration.

Incubation

Incubation is the name given to the time when the conscious mind is not actively working on the problem but the unconscious is. One often does not know if the incubation stage has started until one starts to dream about the problem, either at night or during daydreams, and in these settings new ideas appear. Most of the first ideas are new but do not solve the problem – more time is needed in the incubator. In my mathematical modeling class, where dreams are common during an extended problem solving process, I have a short lecture in which I tell the students not to be surprised if they start dreaming about the problem. One semester, after the lecture, a student came up and said, "I'm so glad you told us that – I thought I was going crazy," Merrill (2003). It is literally remarkable that this excellent student was so unaccustomed to dreaming that she was concerned about them.

During the period of incubation, it seems best to not have the conscious mind too busy. Incubation begins when the immersion in the problem and the urge, necessity, or stress for solving the problem present it to the unconscious for assistance. If the unconscious is silent or unhelpful on the matter, it is often the case that additional conscious work on the problem is needed. This is the case when all the aspects of the problem are not yet present or the problem is too vaguely presented. I have found that if the stress is successfully communicated to the unconscious, but all details necessary are not, nightmares occur as the unconscious tries to imagine what dire consequences will result from not solving the problem. Taking walks and showers, in addition to dreaming of all types, seem to be common incubation methods. It is interesting that to solve a problem you must stop (consciously) working at it periodically. When the solution comes in a flash or a dream, the step of recording this information before it vanishes is important. Many people who have frequent illumination will carry a notebook, as the insights are often transitory.

In the context of scientific investigation, Beveridge (1951) described conditions conducive to incubation (and the intuition and insight that result):

> 1) The most important prerequisite is prolonged contemplation of the problem and the data until the mind is saturated with it. There must be a great interest in it and desire for its solution. The mind must work consciously on the problem for days in order to get the subconscious mind working on it.
> 2) An important condition is freedom from other problems or interests competing for attention, especially worry over private affairs.
> 3) Another favorable condition is freedom from interruption or even fear of interruption or any diverting influence such as interesting conversation within earshot or sudden and excessive loud noises.
> 4) Most people find intuitions are more likely to come during a period of apparent idleness and temporary abandonment of the problem following periods of intensive work ... A hopeful attitude may help.
> 5) Positive stimulus to mental activity is provided by some form of contact with other minds." The contact may be discussions, writing a report or giving a talk on it, reading scientific articles, including those with which one disagrees.
> 6) It is a common experience that new ideas often vanish within a minute or so of their appearance if an effort is not made to capture them by focusing attention on them long enough to fix them in memory.
> 7) It takes time to get your mind "warmed up" and working efficiently on a subject, holding a mass of relevant data on the fringe of consciousness. Interruptions disturb this delicate complex and break the mood. Also mental and physical fatigue, too constant working on the problem (especially under pressure), petty irritations and really distracting types of noise can militate against creative thinking.

Illumination and the use of dreams

By dream, I mean the result of any non-conscious brain activity of which consciousness is eventually aware. Unconscious brain activity takes place at all times, evidenced by instances when ideas "pop into your head." Unconscious activity also plays a role in perception. Our consciousness filters sensory experience to enable us to respond to it in real time. A richer and more complete record of the day is stored, however, as first recognized by Leibniz (1981) – an inventor of the Calculus. Brain activity during sleep is varied in nature and purpose, and far from static (Kleitman, 1963). Some unconscious brain activity is clearly for housekeeping purposes, sorting through experiences and data of the day just past, possibly trimming some and emphasizing others through an automatic process. The importance of REM (rapid eye movement) sleep in both animals and humans in establishing long-term memory and solving complex problems also has strong evidence (Smith, 1996). Dement & Kleitman (1957) also identified the repeated periods of REM sleep as the sources of identifiable dreams. The biological purpose of dreaming (i.e. awareness of the unconscious activity), however, is not so clear. Dreams during REM sleep, and states between full consciousness and sleep, do tend to be identified as the most useful in creative contexts in reports from those who create. For mathematicians and scientists, hypnangogic dreams (when falling asleep) and hypnopompic dreams (upon awakening) seem to be the most useful (Barrett, 2001). Daydreams also fall into this category (Klinger, 1990).

Instructions in how to suggest the subject of a dream and remember dreams can be found in many sources. Barrett (2001) relates the following instructions:

1) Write down the problem as a brief phrase or sentence, and place it by your bed.
2) Review the problem for a few minutes just before going to bed.
3) Once in bed, visualize the problem as a concrete image if it lends itself to this. Visualize yourself dreaming about the problem, awakening, and writing on the bedside note pad.
4) Tell yourself that you want to dream about the problem just as you are drifting off to sleep.
5) Keep a pen and paper – perhaps a flashlight or pen with a lighted tip – on the night table.
6) Arrange objects connected to the problem on your night table or on the wall across from your bed if they lend themselves to a poster.
7) Upon awakening, lie quietly before getting out of bed. Note whether there is any trace of a recalled dream, and invite more of the dream to return if possible. Write it down.

Taylor (1983) discusses recalling dreams and suggests that a primary problem is that the dream happens outside of the normal structures of our waking personalities and consciousness. For that reason, even describing the dream in words can be a problem. The recording, relating, and remembering of dreams is a learned discipline (sometimes culturally taught). Basic dreaming books in this context include Taylor (1992); Garfield (1995) and Mellick (2001). A related discipline is that of lucid dreaming and dream yoga (Taylor, 1983; LaBerge, 1986; Young, 1999). The learned ability to have consciousness present in a REM dream allows one to interact with the dream. Those who have this ability do not seem to benefit in increased creativity (Blagrove & Tucker, 1994). This may be due to interference in the unconscious process by the conscious mind – bringing with it the limitations of the real world where the problem was difficult to solve.

Illumination following incubation can be dramatic or subtle, spontaneous or slowly revealing, symbolic or direct. The examples found in Harding (1948); Ghiselin (1952); Harmon & Rheingold (1984); Inglis (1987); Inglis (1988); Stevens (1995); Barron et al. (1997); and Barrett (2001) illustrate

the variety in admittedly remarkable cases. In my experience, the everyday illumination is much the same, but not every insight has the potential to lead to a Nobel Prize. The difficulty in this creative phase is the translation of that flash of understanding to the real world. Here is where technique in the discipline and the preparation in hearing the voice play the critical role. Koestler describes this phase in very geometric terms.

> *The moment of truth, the sudden emergence of a new insight, is an act of intuition. Such intuitions give the appearance of miraculous flashes, or short-circuits of reasoning. In fact they may be likened to an immersed chain, of which only the beginning and the end are visible above the surface of consciousness. The diver vanishes at one end of the chain and comes up at the other end, guided by invisible links.*
>
> *Habit and originality, then, point in opposite directions in the two-way traffic between conscious and unconscious processes. The condensation of learning into habit, and the automatization of skills constitute the downward stream; while the upward traffic consists in the minor, vitalizing pulses from the underground, and the rare major surges of creation.*
>
> *Arthur Koestler*
> *The Act of Creation, 1964*

Experiencing a block to creativity for those that have been creative in the past is common. The lesion can be at any point along the process. Those who have worked to overcome blocks work either at the preparation stage, redeveloping habit (Cameron, 1992; Tharp, 2003) or silencing censoring aspects of the conscious mind (Cameron, 1992; Kolodny, 2000). It is difficult to detect, from direct observation, where the problem lies, as the only symptom is "no creative output." Another way to visualize a block is as a failure to be open to the creative River. It can be because you have not approached the River (lack of preparation or curiosity), fear of approaching the wild water of the River (fear of loss of control or hearing a censoring voice), inability to swim in the River (failure of practice in listening to the voice), or failure to drink from the River (not accepting the message received). An interesting note is that in mathematics, it is generally believed that mathematicians do their most important work by the age of 35 years. This, I believe, is due to the difficulty in approaching the River.

Modeling in Science Education

As suggested by Hodson (1992), science education has three purposes: the learning of the ideas of science, learning about the history and methodology of science, and learning how to do science. As noted by Justi & Gilbert (2002) each task has at its core the use, critical evaluation and construction of models. Models serve to encapsulate knowledge and their metaphors and analogies are often the language of the construction of scientific hypotheses central to the scientific method. Although present in national curricular recommendations (DfEE, 1999 in England and NRC, 1996 in the US), in science-specific studies (Halloun, 1996, (physics); Tomasi, 1988, (chemistry)), and many discussions of thinking and learning (Justi & Gilbert, 2002) the methods by which the construction of models can be taught has lagged, primarily due to the more individual (difficult to assess) and creative nature of the enterprise. The MARS curriculum (Raghaven & Glaser, 1995) for 6th grade students is one of the projects that explicitly included model building as part of the curriculum. In this project the long time required to develop the necessary skills was noted. It is probably the case that at this age the students had neither the background nor the necessary cognitive ability for the tasks posed. (Or possibly the necessary aspect of play was missing from this experience.)

From the short discussion above, although the role of models in science is clear, their actual place in the science curriculum is not so clear. There is an additional difficulty in that teaching modeling has no clearly defined methodology and most who would teach it may not be practiced in creating models, themselves.

Mathematical Modeling as a path to the creative voice

Davies & Gilbert (2003) have noted that modeling is a creative art that could be used to foster creativity in science and technology education. Of the many types of models, mathematical models present the longest history and case for course-length treatment. Construction of these models require strong understanding of the mathematics being employed and the application area, and an ability to abstract to see past the complexity presented by specific observations.

I am an applied mathematician who has created mathematical models as part of work with scientists, physicians, and engineers over a 30-year career. The necessity to deal with complicated theoretical and practical problems over this period has provided evidence of the importance and usefulness of these models in the laboratory and clinic. My training of Ph.D. students includes having them learn to construct and use models over their years of training. With undergraduates in the sciences, because of the lack of continuity in instruction over their student years, I have focused on the process of creativity – trying to insure that over a one semester course, a recognizable creative event takes place. The evidence of the creative event is the solving of a "hard" problem.

"Computational Models" was a course taught at Marquette University in Milwaukee, Wisconsin, USA from 1975 to 2003 as a semester-length course presented every semester. The course was designed for students in their second or third year in mathematics, mathematics education, engineering, and the sciences with and average enrollment of 18 per semester. I personally taught this course 15 times, supervising about 250 students in the course. The main feature of this course was the requirement to produce a report that describes the solution of a problem of difficulty by the student. Students choose their problem with the assistance of the instructor whose job it is to insure that the problem is "hard" but not impossible given the length of time available and the talents of the student. A hard problem is defined as one that cannot be solved a few weeks and has sufficient complexity to require a model for its solution. Solving the problem, then, is evidence that a model was successfully constructed and utilized. Given that the process of modeling is by nature creative, a successful conclusion to the project is evidence that a creative event has taken place.

Although there are lectures, tests, and homework assignments for the first 6 weeks of the course, which helped the students learn what a model is and how one might use one, weekly 20 minute meetings between each student and the instructor gradually shifted the emphasis to exclusive attention to defining and then solving the problem.

It has been essential over this period to have the students select problems that are of personal interest and whose solution has clear importance. A typical problem may involve solving a problem arising in the family business. Here, the student has inside information, access to necessary data, and motivation for a solution. Many projects came from summer jobs, issues raised in other classes, problems from the city or university, or big problems like pollution and public health. A second essential aspect to this course was the fact that for almost all of them, the course was required. They needed to pass the course to graduate. And, a successful project was required to complete the course. This provided the necessary stress to encourage a creative event. We have also discovered that the helpful, but not directing, presence of the instructor, provided a necessary confidence to the student that the task was possible (otherwise instead of helpful dreams one generates nightmares). The

familiarity of the student with the problem provided much of the preparation for the problem necessary to have the creative event.

In these classes, the creative process is presented as described here at the time at which the project problems are chosen. Students are not generally open to this discussion at the time it is given. They are open to the discussion after the semester is over and they can relate the discussion to their personal experience. I have found that a difficulty in teaching this class is that the students are hesitant to engage in the childish play that I have found essential to the process. They also are not practiced in recognizing their dream and daydream messages from the unconscious.

The result of this class is that everyone produces a report, the "precising" of the insight recieved. Everyone solves some form of the problem they set out to solve. To do this, every one of them had to create and employ some original model. It is my contention that once the creative voice has been found and used, it is available to them throughout their lives.

Bibliography

Amabile, T. (1996). *Creativity in Context*. Boulder, Colorado: Westview Press.

Barrett, D. (2001). *The Committee of Sleep*. New York: Crown Publishers.

Barron, F., Montuori, A. & Barron, A. (1997). *Creators on Creating*. New York: Jeremy P Tarcher/Penguin.

Beveridge, W.I.B. (1951). *The Art of Scientific Investigation*. New York: W.W. Norton & Co.

Bjørkvold, J-R. (1992). *The Muse Within*. W. H. Halverson (Trans.) New York: HarperCollins.

Blagrove, M. & Tucker, M. (1994). Individual differences in locus of control and the reporting of lucid dreaming. *Personal and Individual Differences* 16, 981-984.

Boostrom, R. (2005). *Thinking: The Foundation of Critical and Creative Learning in the Classroom.* New York: Teachers College Press.

Cameron, J. (1992). *The Artist's Way*. New York: Jeremy P. Tarcher.

Cobb, E. (1977). *The Ecology of Imagination in Childhood*. New York: Columbia University Press.

Crain, W. (2004). *Reclaiming Childhood: Letting Children Be Children in Our Achievement-Oriented Society*. New York: Henry Holt & Co.

Csikszentmihalyi, M. (1990). *Flow*. New York, Harper & Row.

Csikszentmihalyi, M. (1996). *Creativity*. New York: HarperCollins.

Csikszentmihalyi, M. & Csikszentmihalyi, I.S. (1988). *Optimal Experience*. Cambridge: Cambridge University Press.

Davies, T. & Gilbert, J.K. (2003). Modelling: promoting creativity while forging links between science education and design and technology education. *Canadian Journal of Science*, 3, 67-82.

Dement, W.C. & Kleitman, N. (1957). The relationship of eye movements during sleep to dream activity: An objective method for the study of dreams, *Journal of Experimental Psycholo*gy 53, 339-346.

DfEE (1999). *Science: The national curriculum for England*. London: Department for Education and Employment.

Fox, M. (2002). *Creativity: Where the Divine and Human Meet*. New York: Jeremy P. Tarcher/Putnam.

Garfield, P. (1995) *Creative Dreaming*, *2nd ed*. New York: Simon & Schuster.

Ghiselin, B. (Ed.) (1952). *The Creative Process.* Berkeley, California: University of California Press.

Gilbert, J.K., Bouter, C., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J.K. Gilbert & C. Boulter, (Eds.), Developing models in science education. (pp. 3-17). Dordrecht: Kluwer.

Goldberg, N. (1986). *Writing Down the Bones*. Boston: Shambhala.

Goleman, D., Kaufman, P. & Ray, M. (1992). *The Creative Spirit*. New York: Dutton.

Goleman, D. (1997). *Emotional Intelligence: Why it Can Matter More Than IQ*. New York: Bantam.

Gryskiewicz, S. S. & Hills, D.A. (Eds.) (1992). *Readings in Innovation*. Greensboro, North Carolina: Center for Creative Leadership.

Hadamard, J. (1945). *The Psychology of Invention in the Mathematical Field*. Princeton, New Jersey: Princeton University Press.

Harding, R. E.M. (1948). *An Anatomy of Inspiration*, *3rd ed*. Cambridge: W.Heffer & Sons.

Harman, W. & Rheingold, H. (1984). *Higher Creativity*. New York: Jeremy P. Tarcher/Putnam.

Hodson, D. (1992). In search of a meaningful relationship: an exploration of some issues relating to integration in science and science education. *International Journal of Science Education*, 14, 541-562.

Halloun, I. (1996). Schematic modeling for meaningful learning in physics. *Journal of Research in Science Teaching*, 33, 1019-1041.

Inglis, B. (1987). *The unknown guest: The mystery of intuition*. London: Hodder & Stoughton, Ltd.

Inglis, B. (1988). *The Power of Dreams*. New York: HarperCollins.

Justi, R. & Gilbert, J.K. (2002). Modeling, teachers' views on the nature of modeling and implications for the education of modelers. *International Journal of Science Education*, 24, 369-387.

Klinger, E. (1990). *Daydreaming*. New York: Jeremy P. Tarcher/Putnam.

Kleitman, N. (1963). *Sleep and Wakefulness*. Chicago: U of Chicago Press.

Koestler, A. (1964). *The Act of Creation*. New York: Macmillan.

Kolodny, S. (2000). *The Captive Muse: On Creativity and Its Inhibition*. Madison, Connecticut: Psychosocial Press.

LaBerge, S. (1986). *Lucid Dreaming: The Power of Being Awake and Aware in Your Dreams*. New York: Ballantine Books.

Leibniz, G. W. (1981). *New Essays on Human Understanding*. P. Remnant & J. Bennett (Trans. and Ed.) New York: Cambridge University Press.

May, R. (1994). *The Courage to Create*. New York: W.W. Norton.

Mellick, J. (2001). *The Art of Dreaming*. Berkeley, California: Conari Press.

Merrill, S.J. (2003). Solving problems: perchance to dream. In *ICTMA 11: Mathematical Modelling: A Way of Life*, S.J. Lamon, W.A. Parker, and S.K. Houston (Eds.), Chichester, UK: Horwood Publishing, Ltd.

Murphy, G. (1958). *Human Potentialities*. New York: Basic Books.

Nachmanovitch, S. (1990). *Free Play: Improvisation in Life and Art*. New York: Jeremy P. Tarcher/Putnam.

NRC (1996). *National Science Education Standards.* Washington D.C.: National Academic Press.

Piirto, J. (2004). *Understanding Creativity*. Scottsdale, Arizona: Great Potential Press.

Poincaré, H. (1915). *The Foundations of Science*, G. B. Halsted (Trans.) New York: The Science Press.

Raghaven, K. & Glaser, R. (1995). Model-based analysis and reasoning in science: the MARS curriculum. *Science Education*, 79, 37-61.

Rogers, A. (2001). *Feeding the Spirit: Dreams, Art and Language in the Elementary Classroom*. San Jose, California: Writers Club Press.

Root-Bernstein, R. & Root-Bernstein, M. (1999). *Sparks of Genius*. Boston: Houghton Mifflin.

Smith, C. (1996). Sleep states, memory processes and synaptic plasticity. *Behavioural Brain Res*earch, 78, 49-56.

Stevens, A. (1995). *Private myths: Dreams and dreaming*. Cambridge, Massachusetts: Harvard University Press.

Taylor, J. (1983). *Dream work: Techniques for discovering the creative power in dreams*. Mahwah, New Jersey: Paulist Press.

Taylor, J. (1992). *Where people fly and water runs uphill*. New York: Warner Books.

Tharp, T. (2003). *The creative habit : Learn it and use it for life.* New York: Simon & Schuster.

Tomasi, J. (1988). Models and modeling in theoretical chemistry. *Journal of Molecular Structure*, 179, 273-292.

Ulam, S.M. (1976). *Adventures of a mathematician.* New York: Charles Scribner's Sons.

Wallas, G. (1926). *The art of thought*. New York: Hardcourt Brace Javonovich.

Young, S. (1999). *Dreaming in the lotus*. Boston: Wisdom Publications.