



GROUNDING THEORY REVIEW

An international journal

Adventuring: A grounded theory discovered through the analysis of science teaching and learning

Katrina M. Maloney, M.Sc., Ed.D.

June 2005

Grounded Theory Review, Vol 4 (Issue #3), 29-58

The online version of this article can be found at:

<https://groundedtheoryreview.org>

Originally published by Sociology Press

<https://sociologypress.com/>

Archived by the Institute for Research and Theory Methodologies

<https://www.mentoringresearchers.org/>

Adventuring: A grounded theory discovered through the analysis of science teaching and learning

By Katrina M. Maloney, M.Sc., Ed.D.

Abstract

The grounded theory of adventuring, derived from the substantive area of science teaching and learning, explains both why scientific thinking is an evolutionarily important trait and illustrates a common thread throughout a variety of teaching and learning behaviors. The core concept of adventuring incorporates the categories of exploring, mavericking, and acquiring and applying skills that are the hallmarks of positive science education. Learning science is difficult due to the higher order cognitive skills required. This study explains how we could be teaching and learning science in a way for which our brains are best suited, and in ways that reach all learners, and encourages the use of adventuring in all classrooms.

Introduction

The grounded theory of adventuring explains behaviors of teachers and learners. This study discusses the psychology/sociology of teachers teaching science and students learning science through a grounded theory analysis of behaviors, and elucidates the biological process of thinking by discussing changes over time to the human brain's physiology and chemistry. In connecting the behaviors of science thinkers to the biology of the brain's hardware, this work explains how we could be teaching and learning science in a way for which our brains are best suited.

Adventuring, as a core concept, contains the three categories of exploring, mavericking and acquiring and applying skills. Ten dimensions of adventuring are also discussed in this study, identifying conditions, strategies, types and consequences of adventuring. Although the theory of adventuring was discovered through an exploration of the substantive area of science teaching and learning, as soon as the theory was shared with others, it became apparent that adventuring happens in a wide variety of situations and conceptualizes latent patterns of behavior found in many learning scenarios.

Rationale: Why is Learning Science Difficult?

Studies summarized in *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1991) and *Shaping our Future* (National Science Foundation, 1996) state unequivocally that there is a need to teach science well to promote the type of scientific literacy necessary in a complex and increasingly global society. Science is in our everyday space. The imperative to be active decision makers in our country is a right and, as such, carries responsibility. If we forfeit that right and deny the importance of science education for all learners, we do a grave disservice to our communities, to our country, and to our planet.

The higher level cognitive demands of science courses are very difficult for a developing mind. Specifically, science courses blend math skills and linguistic skills, higher order cognition skills of hypothesis generation, analysis and modification. Science courses require rote memorization, sequential organization, and sustained attention to detail. Understanding science texts and participating in class discussion require sophisticated receptive and expressive language abilities (Levine, 1987). Troublesome issues for students identified in college science classrooms by professors include: use of scientific tools (hardware such as microscopes, centrifuges, incubators, balances, pipettes, measuring instruments); science literature (dichotomous keys, graphs/tables/charts, textbooks, journal articles, popular press items); and the cognitive skills of analytical thinking such as basic questioning, prediction, the hypothetical-deductive process itself (proceeding from general concepts to specific events, or, in other words, identifying the causes of results), organization of data and concepts, creating and/or reading graphs and charts, the recursive nature of science inquiry, and the possibility of change in facts/theories/hypotheses. Students bring various strengths to their work in the cognitive realm of science, but severe deficits in background understanding of basic scientific processes are obvious (personal communications, colleagues at a small liberal arts college, 1999).

In addition to the list above, a skills-and-inquiry-based text and study guide (Milani, 1987) identifies the following as “Science Cognition Skills”:

- observing
- describing properties and changes

- using data tables
- inferring from data
- using models to understand ideas
- identifying variables
- making predictions from hypothesis
- interpreting data to test hypothesis
- revising hypotheses
- statistics (use and understanding)
- making graphs--organizing data for
- observing to find evidence for a concept or idea
- classifying

As is apparent from the observations and teaching experiences of college professors and literature written for classroom learning, there is a complexity to the cognitive skills needed for successful scientific thinking. Other elements involved include development (physical, social, and intellectually maturity), biology (the health and “wiring” of the brain/mind itself), psychological, cultural, and emotional aspects.

How we teach science today and to how we could be teaching science if we understand how our brain/minds have evolved is a complex as well as complicated issue. This grounded theory investigation of the social activity of teaching and learning helps support the types of changes in education imperative to our success as a society of thinkers.

Method

The grounded theory (GT) method, used in this study, involves a process of discovery that begins with a broad topic. Investigations in GT start with a grand tour question, one that is deliberately open-ended so that participants reveal processes, assumptions, or behaviors that are important to them, without prejudicing influences from the researcher. Live interviews, classroom observations, published interviews and science literature were analyzed and incorporated into the final theory of adventuring. The open-ended nature of the initial data collection provided rich sources of material. The constant comparative analysis methods integral to the GT method were used to analyze all sources of data in this study.

The GT method is uniquely suited to the study of the complex social construct of science education, (and indeed, other areas of

education as well) because it is generated from data, not produced by means of hypothesis verification. Grounded theory inductively and systematically discovers theory from data. It generates rather than verifies theory. Constant comparative analysis is employed in grounded theory analysis to discover variables that might explain the widest variety of behavior (Glaser, 1992). When an answer seems imminent, the challenge is to keep asking, 'How do I know?' (Personal communication, Odis Simmons & Toni A. Gregory, June 2001). In this manner the analysis is kept honest to the data. The constant implementation of strict comparison is the prime reason GT research is rigorous, true to the data, and ultimately effective as a social research tool (Glaser & Strauss, 1967; Glaser, 1992; Simmons & Gregory, 2003).

Education is a social pursuit and is both a complicated (made up of more than two elements) and a complex (interconnected) system. Grounded theory analysis uses the cognitive skills of comparison, spiral reasoning (recursiveness) and a systematic, rigorous approach to data collection and analysis in order to approach and identify an emergent theory. Data analysis informs theory and vice versa (Glaser, 1992). To begin a GT study, questions asked include "How do the parts (data) combine into a whole (theory)?" and, "How do the everyday behaviors shown through what the interviewee chooses to talk about indicate a theory to explain why these behaviors happen?" In contrast, in scientific method research (used by the natural and physical sciences), an hypothesis is generated after observation, then tested and verified or modified according to the data (Campbell, 1996; Kent & Coker, 1992). Inductive and deductive reasoning skills are used in GT analysis, and are both useful and necessary when considering complex systems of education. The use of a conceptual theoretical model, rather than either a qualitative or quantitative tradition alone, yields a rich, relevant, workable and eventually modifiable theory.

Grounded theory, as a discovery system, is most suited to the study of the intricate and controversial system of education. Educators and learners are a widely diverse group, and there are many opinions about the problems and successes of our education system. GT methods suit this at times inextricable maze of a system by maintaining the strict adherence to description and coding of behaviors while holding at bay preconceptions, to get to the root of the matter: How can we conceptualize the wide variety of behaviors inherent in teaching and learning? The theory of adventuring is one explanation for the behaviors exhibited by science teachers and learners.

The Theory of Adventuring

The three major categories of adventuring are “exploring,” “mavericking,” and the “acquisition and application of skills.” Any person who actively seeks out physical or mental challenge in new ways, proceeds to overcome those challenges in ways that are not conventional, and then applies the new knowledge to another task is adventuring. The purpose of adventuring is not to produce an end product (although certain actions may have an endpoint such as laboratory experiments). Adventuring behaviors have a deeper objective than just to get somewhere, do something, or make a mark on an actual or metaphorical mountain-top. The point is the journey, the challenges that arise during the process, and the knowledge that, even for an expert in the field, something new is to be learned each day or from each event. Each new learning impacts others, and the results or consequences of the present may appear at a later time.

As Nobel laureate Barbara McClintock stated:

People get the idea that your ego gets in the way a lot of time--ego in the sense of wanting returns. But you don't care about those returns. You have the enormous pleasure of working on it. The returns are not what you are after.
(Bertsch McGrayne, 1998, p.168)

A professional woman interviewed said that she was not interested in research: “Something or someone always gets hurt--slugs or chimps, whatever.” She preferred to practice her science, to read about clinical trials, but to actually do her job was more rewarding than seeking answers to hypothetical questions. Her experiences in “getting my hands dirty” were more important than any lab work she could have done. Referring to academia, she said: “It is not where you life is--it's your work that's important.”

In the context of teaching and learning science, adventuring occurs in classrooms on the part of the instructor and the student, in laboratories, and in the field. Each of these environments holds the necessary atmosphere for the dimensions, categories and properties of adventuring. In a dynamic classroom, the instructor and students each need to explore, have fun, do tasks, and acquire skills to be used in the next task. Most science courses have some component

of laboratory experimentation, and this is recognized as an important hands-on teaching and learning technique (NSF, 1996). Most students like lab activities. The lab serves as an alternative to the less multimodal aspects of the classroom lecture model.

Field workers (veterinarians, foresters, biological survey workers, etc.) have the opportunity to adventure in the best setting of all. The natural world is full of opportunities for adventuring, and indeed is the original stage for such behaviors. For instance, Jane Goodall pioneered primate ethnology by conducting observations in the chimp's own wild habitat rather than in artificial environments such as zoos in the 1960s (Montgomery, 1991).

Research laboratory workers, both principal investigators and research assistants, have opportunities to adventure every day in their work. A successful research scientist working in a laboratory, who is a leading figure in her field, talked about her favorite thing about her job:

Finding out something new that nobody ever knew before. The whole process of being involved and finding out things and the excitement of discovery is absolutely tremendous.

Conditions of Adventuring

Having control over one's own schedule is important to successful adventuring. Labs, classrooms, the field, and generally nontraditional environments are conducive to adventuring. The flexible daily schedule may fit a person's own circadian rhythm, or creative cycles. Scientists might put in 14 or more hours a day in the laboratory (Sonnert & Holton, 1995), college professors may hold classes in the early morning or evenings. Legend has it that Buckminster Fuller dreamed of the structure of carbon now called a Bucky-ball, and "Eureka!" -was uttered by Archimedes in his bath. A research scientist remarked:

There are days that I get out in 8 hours and there are days that I don't. A lot of times I do more like 10 hours...but there is flex time as long as you get the work done you can be flexible about your hours. I don't have to be there at 6:30 a.m., but I'm just much more of a morning person and I live close.

Creative thinking is fostered in adventuring scenarios. Although nonlinear thinking is not traditionally considered a science cognitive

skill, it is very important that there be freedom from the institutional structure to utilize creative methods. A worker in a research lab said:

Every once in a while they [drug companies] come up with something new like now you need to have a [specific product] which is what I helped develop...They wanted to get it on the market, so they had three existing [products] that they thought would work, so they gave them to me and said, "Figure out how to make this work", so that's what I did! It was cool!

Teamwork is an available option in adventuring. Several interviewees mentioned the social aspect of doing science.

[Science is a] very social endeavor...somehow I've done fairly well with people in my lab in terms of keeping them happy...because of the fact that they feel that it's a positive environment.

Group work is often encouraged in science classrooms. Lab partners are almost always assigned, to build cooperation and teamwork skills in students, but also because some tasks need two people to accomplish. In a marine biology class visited, the students were paired up so that one could take notes while the other observed snails. Sometimes teamwork is integral to the event, such as teacher-student dynamics, team product development, physical assistance in the field, and so on. At other times the scientist is alone, experimenting with different ways to answer a question, or simply cogitating on the data. "I enjoy mostly working by myself or with a small number of scientists and students," said one participant. Jane Goodall isolated herself from other humans in order to observe the wild chimpanzees in their natural environment (Montgomery, 1991). Barbara McClintock developed the "capacity to be alone" (Fox Keller, 1983, p. 17) from an early age, and this strength supported her research endeavors throughout her life.

Part of adventuring is the *serial completion of tasks*. There are things to do, places to go, people to see, and ideas to contemplate. There are classes to teach, research to conduct, clients to meet, reports to write. Each task is time delineated with the beginning, middle, and end as discrete. The tasks may be related, and a series of tasks comprising a project is a key component of adventuring. (See below for a complete description of variable tasking.)

In adventuring, *the individual has control over Intellectual*

processes and personal motivation. In adventuring, the day-to-day accomplishment of goals is self-regulated, self-directed, and self-satisfying. For instance- laboratory protocols are designed by researchers themselves (“With this product, I made the protocol, so everyone follows the protocol I came up with”); professors design and implement their courses (“I do a lot of independent studies...I get out there with curriculum development work, bio majors who want to be bio teachers, for instance”); and field workers have only themselves to rely on when confronted with tasks to accomplish or problems to solve. In adventuring, internal motivation to succeed, grow, use new skills, and/or relate old knowledge to new challenges is strong.

Adventuring is not about being safe and comfortable, it is about actively seeking challenge: *risk is available.* Jobs that are intrinsically risky are considered fun and desirable: The challenge is the attraction that maintains high interest and engagement. Risk may be intellectual, as for this research scientist: “In choosing a subject, there has been a deliberate and very strong desire to choose something that can be completely one’s own. And this is clearly true with me, in terms of what I’ve chosen, even if it is high risk.” And risk can be physical, as in exploring a relatively inaccessible ecosystem, working in the field with large animals, or working alone in the woods.

Risk is not necessarily involved in daily survival needs--basic bodily needs such as food and housing are met, so that one can concentrate on higher order intellectual activities.

There are three types of *freedoms* associated with adventuring:

- *Mechanical freedom* comes about by gaining the knowledge of tools to DO actions/tasks. A professional scientist learned all the skills she needed to go out and do her job, and therefore could go beyond the basics in her everyday work. A college professor said, “[my graduate experience] is really driving who I’m becoming as a teacher.” The abilities gained through mastering skills allow adventuring to be realized.
- *Expressive freedom* is made available when creativity is unleashed and allowed, encouraged to flourish, and focused to use as a tool. Innovation, approaching problems from creative points of view, and being encouraged to do so is important in successful adventuring. After students are taught certain skills (i.e., observation, hypothesis development), then “let loose” on a project with support for creative approaches, adventuring

happens. Discussing the undergraduate professor for whom she became a research assistant, Barbara McClintock said, "He just left me to do anything I wanted to do, just completely free" (Fox Keller, 1983, p.39). The early trust her supervisor placed in McClintock fostered her creative abilities and encouraged her to have faith in her own intelligence.

- After mechanics are learned and creativity unleashed, *mental freedom* to use all of the exploring, mavericking, and acquisition of skills of adventuring at once is possible. After Rosalind Franklin left Kings College (where she had discovered the structure of the B form of DNA in 1951), she had a lab at Birkbeck College and a project to study viruses. At Birkbeck, she had grants, assistants, space, and the respect of her colleagues. Franklin proceeded to publish 17 papers on virus structure between 1953 and 1958, a prolific record (Sayre, 1975). The combined conditions of Franklin's extensive background in x-ray technique, the availability of an interesting and unique problem to which she could apply her creative skills, and the conditions which allowed her to flourish and apply all of her skills exemplify the freedoms of adventuring.

Strategies of Adventuring

In order to maintain the adventuring state, scientists take on many different responsibilities (teaching load, independent student projects, writing, sitting on committees, presenting at/attending conferences, projects in a lab). Interacting with colleagues of like mind for mutual discussion and understanding also occurs. Socializing with peers is fun, interesting, and synergistic: New knowing can come from such interactions. A strategy of maintaining the adventuring state for teachers may be taking a lower paying teaching job rather than pursuing research at a university. Adventuring requires flexibility in daily schedules as well as broader considerations such as geographic location or job description. A college professor said:

This is one of the best jobs in the world as far as I'm concerned, because, if you were at a large research institute as a professor, you know, I'd have a lot less flexibility...here if I want to do my scholarship on an organism one year, I can switch to something different the next year.

Furthering one's own professional development by attending

conferences, presenting, reading others' work, and moving to a geographic location that has the situation desired with all the proper elements are additional strategies of adventuring. Adventuring teachers or researchers learn skills from their own education, both formally in graduate school and informally as they teach in their fields. The skills thus acquired are vital to the recursive nature of adventuring. Each skill learned and applied gathers others to it and advances the spiral loop of exploration and discovery.

Types of Adventuring

In the realm of scientific teaching and learning, there are two main types of adventuring: (a) teaching, which, as an added result, prepares others to adventure into science inquiry, and (b) researching or "doing science." Both types are active, seek change, and impact others through the combined behaviors of adventuring. Adventuring through teaching incorporates action agents-- meta-catalysts seeking out events and acting upon such for change. "Teaching adventuring" acts after, beyond, behind, along with, and among other people to bring about new knowledge, and in so doing is strengthened and changed in preparation for the next event. As a meta-catalyst, teaching adventuring is not used up during a reaction but grows stronger and more expert as it travels long the loops of adventuring. A college professor said:

I'm not producing much science, but I'm helping produce scientists...so I feel like I have much more impact on my field in this position than I would if I was a practicing, doing research, although I try to do some of that, but you know when students come in and do all these independent projects, you know it takes away from my getting my research done, but... through them I get to explore about other new things...so my motivation [in taking on independent students] is to have those students go off and do such great things afterwards, that huge amount of confidence they gain from working one on one with you... so you get the direct mentoring and also this opportunity to explore something that's important to them.

Researching adventuring may or may not incorporate active teaching. Laboratory assistants, post-doctoral appointments, or student interns are sometimes present in laboratories or the field,- but for the most

part, researching adventuring is focused on solving problems. Franklin and McClintock studied DNA to answer specific questions (Fox Keller, 1983; Sayre, 1975); in commercial laboratories researching may be done to create product; in ecological or field research, observation is employed for better understanding (Montgomery, 1991). Researching behaviors relate directly to adventuring by being examples of exploration, skill application, and creative problem solving. The mechanics of adventuring include overlapping, recursive, branching, confluence, compiling, creating, and synthesizing skills, all of which are deliberately taught.

Consequences of Adventuring

The positive consequences of adventuring include a sense of fulfillment in experiencing a full life of the mind. Fun and playing are high interest motivators, and those who adventure seek out situations wherein fun is a component. When adventuring, a person achieves satisfaction of doing what s/he is good at, and has a sense of freedom and control over his or her own intellect and career trajectory. The integration of skills develops self-confidence, and when choices are available they are often self-identified: "I love my job!" was said repeatedly in interviews. The participants felt that it is rewarding to do something they love, and to do it well.

There are negative consequences of the choice to pursue adventuring. Long days in the classroom and/or lab, tiredness, burnout, or hyper-focus can produce an imbalance in the mind/body/spirit realms, stress, illness. There is a need to protect one's work from potential plagiarism, and time management is problematical, "There is never enough time to do it all", "It's hard to balance it all ". For most, there were personal choices regarding partner relationships, family, geographic locations, travel, on so on.

Yeah, I had to make choices after [grad] school and it was hard, it was hard to leave a relationship, but I hated [where she was living]. I just had to live in the country, so I could have all this and develop my practice, too.

The Categories of Adventuring

The three main categories of adventuring are exploring, mavericking, and acquiring/applying new skills and knowledge.

Exploring

In adventuring, teachers and learners of science explore their ways into mysteries, and use skills to understand how things work. Exploring involves questioning. Sir Edmund Hillary, the first European (and most public figure) to climb Mount Everest and return, was clearly questioning the formidable mountain environment for scientific and personal reasons (Morris, 2003). The botanists and anthropologists who opened the western world to Africa, the secrets of ancient Egyptians, the evolutionary origins of humans, Armstrong and his colleagues who stepped on the soil of our moon-- these men and women exemplified exploration in the name of science. Indeed, the brave, talented, knowledgeable, and well-backed Lewis and Clark expedition may be the epitome of our cultural icon, The Explorer (Duncan & Burns, 1997). Ultimately, contribution to scientific knowledge, and therefore a greater understanding of humanity's place in the global system are the goals and objectives of exploring.

A college professor interviewed said: "I still want each student to find their strengths and to have a well-rounded experience like I had during my PhD." Her students had the opportunity to explore a variety of topics before they chose their senior thesis. "You give them an opportunity to be involved in some kind of project and they find they really enjoy that. It's supposed to be a time of exploration." In two high school science classes observed, students actively explored live organisms. In a marine biology class, students were given live snails and asked to design an experiment with them; in a biology class, students were shown cryptogams and asked to observe the structure and form of the various specimens.

A Shift from Fear to Curiosity: The First Scientific Questions

The hominids *Homo habilis*, *H. erectus*, and *H. sapiens neanderthalensis* began their extraordinary evolution toward modern *Homo sapiens sapiens* in a milieu that included rapid climate change and increasing diversification of all life forms some 1.5 million years ago (Wilson, 1992). The increased use of symbolic language, communication, social order, representative art (Donald, 1991), and the beginnings of science adventuring thinking happened simultaneously during the mid to late Pleistocene epoch. Brain anatomy and function, particularly the amygdala response to stimuli¹ and the enlarging prefrontal cortex², were essential for the development of scientific cognition in

the hominid. Adventuring behaviors probably evolved as questioning, discriminating, and exploring the environment (rudimentary “scientific thinking”) became the normal behavior of the hominid. Donald (1991) described the evolution of the *Homo* brain by noting three anatomical markers in the fossil record: (a) the rise of bipedalism at approximately 4 million years ago, (b) a significant enlargement of the skull between the species *Australopithecus* and *Homo habilis* at 2 million years ago, and (c) a second increase in skull capacity (and therefore a larger brain) with the change from *Homo erectus* to archaic *Homo sapiens* at 120,000 years ago. It is probable that a shift in the hominid response to an alien object or event happened due to the animal’s interaction with an increasingly diverse environment, and resulted in exploration and the beginnings of adventuring behaviors.

From the “immediate flee” response to the unknown, *H. sapiens neanderthalensis* developed curiosity and discrimination: “What is this? Will it help or hurt me? Is it poisonous or eatable?” The animal now experimented, tested, and explained its surroundings. Ultimately this shift led to large brains, distinct culture and language, scientific thought processes based on the possibilities of the unknown rather than fear of the unknown, and the adventuring behaviors exhibited today by the large brained, sophisticated *Homo sapiens sapiens*.

Fun

The property of fun includes having interesting and new issues to work with. Through experimenting, discovering and researching a variety of issues, interest is kept high, leading to strong motivation to continue the exploration and sustaining the fun. Sometimes having fun is solitary, sometimes experienced with teamwork. The freedom to play, have fun, and the accompanying self-autonomy is an essential element in exploring.

I love teaching, it’s fun.We did some stuff on plants, and the genes, I liked the genes, it was fun. It was interesting to see the particular things, vertebrates, phylums, cool, yeah, we dissected a starfish...before that we did mealworms, but those weren’t very exciting, those were boring...Oh we did snails, too. I had a snail friend Larry; we did stuff with them, and wrote a report.

Play

Curiosity is fun. An integral aspect of the cogitative and behavioral shift from fear to curiosity was the element of fun. From the earliest mentions of games by the ancient Greek writers to the research conducted at universities on children's play development, play theory has emphasized the presence of curiosity in the playing individual (Levy, 1978). Levy established three criteria for the definition of play: intrinsic motivation, suspension of reality, and internal locus of control. Humans are stimulus seekers, and will distinguish among the intensity, meaningfulness, and variation of play activities. "Play is the behavior that maintains optimal flow of stimulation for the individual" (Levy, 1978, p.132).

Play is spontaneous, free form, can occur with others or with one's self, and is creative. Gaming is a zero-sum event (I win, therefore you lose), is organized or rule based, happens against others, and is structured. Both playing for the sake of playing, and gaming with rules occur while exploring in adventuring - playing around, playing with, messing around, having fun with. One working scientist interviewed stated that fun is a corporate fundamental value that she was rated on in her yearly evaluations for promotion. In adventuring, the element of fun is important for maintaining a high level of interest and therefore is a motivating factor. Each one of the interviews studied mentioned fun or the pleasurable nature of work.

Levy's (1978) first criterion for the definition of play is that the behavior has intrinsic motivation. Play is not forced, structured, or bounded by external forces. Play disintegrates into duty if rewarded. In adventuring behaviors, there is a strong internal drive--a passion for the work that at times exceeds common sense regarding the balance of time/effort and direct compensation, financial or otherwise. In fact, adventuring may put a person in a position of lower financial compensation, acceptable because of the wish to maintain the adventuring state. Fulfillment, happiness, the sense of well being, and tangible contributions to the greater good are attributes of adventuring that are not externally rewarded. The development of play behaviors in children is an important precursor to having fun in adventuring situations later in their academic or professional lives.

Variable Tasking

Variable tasking encompasses behavior that occurs in laboratory investigation situations. Variable tasking involves doing a number of

different tasks, sometimes simultaneously. It is fun, it has variety, it has novelty, and each step has rules. It is a game. There are parameters around each task (rules), steps that must be taken in sequence. There are time boundaries (an experiment may be timed for reaction/ etc.), or there are external time pressures (got to get it to market; beat the other scientists to publish; the class period is only a certain number of minutes long). There are protocols/processes to follow that are important for replication and for learning.

Variable tasking also has an end point: There is a result. This result informs the next task (often, if the variable tasks are a series of experiments, each builds on the previous). A product, a new hypothesis, a variation of a theory, a new something is produced. Multi-tasking is characterized by tasks that are not necessarily connected, whereas variable tasks are interrelated, sequential and/or recursive. Behaviors that illustrate variable tasking are those conducted in the laboratory, such as experimenting, where tasks are serial and orderly. Training is necessary for the use of instruments (microscopes, cameras, etc.) and cognitive skills are required, particularly the ability to follow protocols in a step-wise manner, and the ability to question the fitness of an event. A research scientist described her day:

I can come in and run a test, organize it, take a break for lunch then do the assay in the afternoon. If I can finish my assay early enough when I can get back to my desk for a couple of hours, and either read a report, write a report, do my data, go to a meeting.

The teachers observed engaged in variable tasking by having clearly defined sections during the 45-minute class periods. For instance, in a chemistry class, the teacher started with the review of a test taken the previous day, then introduced new material, then had the students talk in small groups, then reviewed what they had come up with. Each task had a defined beginning, middle, and end, which was explicitly identified by the teacher for the students. In a marine biology class, again, the teacher had clearly defined sections to the class period: preview of assignments and activities to come, preview of the day's activity and the activity itself.

In each class, the tasks had parameters of time (10- to 12-minute intervals), a clearly defined process for covering the material, and an end point defined both by the class period allocation but also by the completion of the task. Each task was related but could stand alone.

Incidentally, this process modeled scientific investigation for the students by explicitly identifying tasks to accomplish and then carrying out the tasks.

The following characteristics are found in variable tasking: organization, interest, skills, flexibility, high energy, patience, sometimes teamwork, independence, confidence in self, confidence from peers or supervisor, strong sequential thinking, and creative thinking. These are similar to the “science cognition” skills identified by Milani (1987) in a study skill workbook (see introduction). Play also relates to the exploring nature of variable tasking. The high level of interest and resulting stimulus, time parameters, and an end result are similar to the process of playing a game. Many games have strategy, a linear progression of events, and an eventual outcome that parallel the experience of a scientist adventuring in a laboratory. For instance, card games have rules and laboratory experiments follow protocol; card games can be played solo, in pairs or groups, and an individual scientist or the research teams work separately or together; card games have a winner at an end point; laboratory work has results to be analyzed and reported in a final document.

Playing around with data and ideas in the tangible world or inside one’s head is not particular to scientists. What makes these behaviors interesting and adventuring is the nature of the thought process. The questioning, observation, experimenting, and analyzing of the exploring dimension is highly creative and risky. The property of mavericking explains the type of exploring that makes adventuring applicable to science teaching and learning.

Mavericking

Scientists are curious; they seek adventure and answers to explain the natural world, the “the other”, “ the unknown”. In ancient times, this mode of thinking may have been an imperative to survival, but at a more recent point, it became a luxury. Some cultures today value this way of thinking so highly that educational institutions are required to teach children scientific thinking. For example, each public school child is exposed to a variety of natural sciences in the United States general curriculum³, and is expected to be scientifically literate by the end of the legally mandated schooling period (AAAS, 1991; NSF, 1996).

The mavericking category of adventuring includes taking a stand

that is independent from others in a group. Accepting challenge, taking risks, and solving problems creatively are important, but the distinguishing behavior in mavericking is that exciting and unusual experiences, either mental or physical, are *actively pursued*. Properties of mavericking include actively seeking hard work and advancing into unknowns (whether it be an hypothesis, a forest, or a classroom) actively, deliberately, and with preparation.

People think that it must be really horrible in science when the idea that you have turns out not to be true, but I find the opposite almost--because when what you thought was going to happen isn't true, you're surprised. And I find that really great! I love it!

Mavericking may include pursuing a different career path than expected, or being viewed by others as different.

Other members of my family think I'm sort of weird because I didn't get married ... the typical type of thing... [growing up on a farm] it wasn't the kind of 9 to 5, five days a week existence that seems to be the general norm now--certainly something I still can't do.

When I was in high school, I was not a particularly social person; I had friends, but they were all slightly odd people with unusual aspirations.

Challenge is exciting and fun. Speculation is joyous. Thinking about things from different angles, being open to new ideas, and continually moving onto the next event are important properties of mavericking.

[in] some areas [of teaching] I feel really confident, and some areas, I'm like whooooo! what have I got myself into?? So I'm pretty adventurous as far as that goes, I don't mind just trying something else, I try to be as responsible as I can, like the course [a new class] that I'm teaching right now... it's not the typical type of assessment that I'm used to doing, so that's what I mean by trying something different, all my tools of the trade don't work in a course like that. What do people do when they teach a course like this? [laughs]...so I'm willing to try certain things.

Being brave, open, and curious; having self-confidence, drive, energy

and passion for work all distinguish the category of mavericking.

My friend C and I tried to get them [snails in their experiment] to race...hers against mine, along a ruler to the other end, but it didn't work, they were climbing all over the rulers...but we tried lots of things.

Mavericking presupposes that physical and basic survival needs are fulfilled (one's salary covers the rent) and that there are more important, interesting, and fun tasks with which to fill the days. In addition, mavericking behaviors are by necessity highly creative. The type of thinking that characterizes and informs mavericking may be a byproduct of a personality style, but the behaviors that encompass mavericking in the adventuring context are supported by deliberate instruction in skills training. The acquisition and application of specific cognitive and mechanical skills that are necessary to mavericking are discussed below.

Acquiring and Applying Skills

A new scientific theory is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction or prior theory and the re-evaluation of prior fact, an intrinsically revolutionary process that is seldom completed by a single man and never overnight. (Kuhn, 1970, p.7)

The category of acquiring and applying skills includes the properties of tool use (both cognitive and mechanical), absorbing lessons, and foresight. Acquiring and applying skills is fun, creative, and satisfying. As a person gets better at a skill, applies it to the task, game, or adventure, s/he becomes satisfied and challenged at the same time. S/he wants to do it again, do more, take on the next question, seek new adventures--strive, conquer, and apply to a new scenario. Each of the interviews examined for this study exemplified these behaviors through curiosity, passion, and alternative approaches to discovering and researching scientific questions.

The recursive nature of acquiring and applying skills requires behaviors that build upon one another in a constant, spiral, and integrated way. Combining previously unconnected elements to synthesize and converge theory is the basic nature of scientific inquiry.

I do think that science, science thinking requires a certain training of the mind, at least for me it did. I have my science side that thinks through logically, then I have my other side that is a release from that way of thinking, so I don't **have** to think that way...a lot of folks don't understand that it took a lot of training to do that, and that a lot of our students can't just pick up and think like that.

Tool Use

Acquiring and applying skills through tool use happens in both the cognitive and mechanical realms of behavior:

- Cognitive tool use (language; ability to synthesize, recombine, and recurse; mathematics).

In order to relate the cognitive skills of *Homo sapiens sapiens* to the behaviors of acquiring and applying skills, it is important to understand the evolutionary development of the hominid brain.

During the Pleistocene epoch, (12-1.5 million years before the present) earth's climate was highly varied. In the north, glaciers came and went; in the south, torrential rains called pluvials stopped and started, and there was great diversification among species in response to environmental change (Morgan, 1972; Wilson, 1992). The early hominid *Australopithecus* eventually became extinct as hominid radiation (diversification of the species) increased and *Homo* species became dominant.⁴ The animal evolving into *Homo sapiens neanderthalensis* had to develop a toolbox of cognitive skills to deal with the variety of climatic conditions, rivals, and food sources. Buss (1999) stated that humans evolved psychological mechanism (sets of procedures) designed to take in specific information, transform such information through decision-making rules (if...then...) into output that solved an adaptive problem faced by the animal.

For instance, the hominid had to create a question in order to make a decision about a food source: "If I eat this, will I *then* be sick?" The formulation of questions involves a more sophisticated cognitive relationship with the environment than previously needed. As problems became more specific, psychological mechanisms tailored to such events evolved, leading to behavior

which was flexible, adaptive, and extremely complex (Buss, 1999). It was during this time that scientific thinking became necessary for the long-term survival and ultimate evolution of the hominid brain into the magnificently complex mind present in *Homo sapiens sapiens*. Without the cognitive tool of questioning, adventuring is not possible, and without language, science is not comprehensible.

Donald (1991) theorized that human language developed in tandem with human culture. “[Human culture] is [an] integrated pattern of adaptation, a complete survival strategy. It forms the larger framework into which various cognitive components ...including language must be fitted” (Donald, 1991, p. 201). Language started from concrete, environment-bound, and episodic culture in the early hominid groups. As *Homo erectus* developed the larger brain, vocal apparatus, and more complex social organization (including cooperation in procuring food), a cultural shift occurred. Thus a mimetic culture utilized gesture to represent action. As time advanced, the mimetic culture began to integrate knowledge and develop mythic representations to “explain” natural events, and to record behaviors (Donald, 1991).

Archaic humans developed linguistic speech as vocal organs became more complex and skulls modified to provide space for a tongue, larynx, and pharynx. External storage for memories (pictures represented things) and theoretical construction began to emerge at this time (Donald, 1991). Symbolic language, both written and spoken, are essential cognitive tools for adventuring. Scientific language is distinct from the jargon used in other academic disciplines, and is often reported as a significant barrier to science learning for students (AAAS, 1991; Levine, 1987).

- Mechanical tool use (scientific instruments, computers)

Basic training on methods of using scientific instruments in the laboratory or field, computers, measuring devices, and so on are important aspects of acquiring and applying skills specific to the task at hand. A participant talked about the different activities she did in class to learn science: experiments with living organisms, dissections, memorization, crossword puzzles, tests, quizzes, “hands-on games,” videos, slides, writing reports. Also, students had pets for which they had the responsibility of feeding, observing, and experimenting with while keeping them alive.

Other skills taught were graphing, using mathematics, taking notes from the board, reading scientific language. One student explained what was covered the year before:

Temperature and time, graphing, seeing how the temperature rose, how long it took, here's my lab report: "prove the density of water", graphing, yeah, we do that in math, too.

Absorbing lessons

Learning from parents, mentors, teachers, or colleagues and taking advantage of opportunities and developing foresight are properties of acquiring and applying skills.

I never had the type of advice that, oh, girls don't do that sort of thing. Any kind of biased upbringing just never occurred to my parents.

My Ph.D. experience was wonderful because I had a great advisor: Dr. Y-- was great, she didn't throw me to the wolves... but my postdoc was disastrous due to a witch of an advisor...it was horrible, she had no patience, was mean.

Childhood experiences impact the development of skills. One interviewee described "playing" as picking up a volume of the encyclopedia:

I remember I would often pick up H because it had horses in it, but once I was in H, I would read about Hindus, I would read about what ever....and that somehow fed into getting interested in more advanced stuff. It's not that the actual material I was reading was significant, but it gave me a sense of connectedness later, with things that really were advanced.

Acquiring skills both cognitive and mechanical, and then applying such skills to science teaching and learning can be placed within developmental considerations, and should be carefully considered within educational contexts. Adventuring, both in and out of the classroom, may hold significant importance to advancing science education change.

Discussion

What is “scientific thinking”? What is scientific language? Why do we distinguish between the language of teaching humanities and teaching science and mathematics? Our universities are divided into schools of Humanities or Sciences, and it is rare that a person excels in both realms. But why do we make these distinctions and what ramifications does this segregation have to how we teach, and how we learn? The answer lies in the development of theoretical symbolic and highly complex language developed by archaic *Homo sapiens* and refined, expanded, and perfected by *Homo sapiens sapiens*.

In our current educational system, according to Donald (1991), the *narrative* mode of thinking is represented by the literary arts, and the *analytic* mode of thought in science, law, and government. Narrative and mythic modes of thought attribute significance to events by modeling and linking by analogy. These processes are attributed by Donald to the ancestral mimetic culture of the Upper Paleolithic and Neolithic time periods, and are encompassed by the more sophisticated analytic thought. Products of *analytic* thought are formal argument, systematic taxonomies, inductive and deductive analysis, verification, differentiation, quantification, idealization, and formal measurement. Theoretical thought is the highest level product because it is a system which predicts and explains (Donald, 1991).

Science education to date has focused on mastering content: facts and vocabulary must be memorized and spit back in laboratory reports and on examinations (Byrnes 1996; Kuhn, 1970; NSF, 1996; Polloway & Patton, 1993; Wyckoff, 2001; Shepherd, 1993). The traditional teaching of science to undergraduates, according to Wyckoff (2001), is through lecture. Wyckoff maintained that this reliance on a clearly demonstrated ineffective teaching style is the major limiting factor in the quality of science education in the United States.

Scientific thinking is characterized by certain reasoning processes: deduction, induction, inference, interpretation, systematic classification, recursiveness, receptive and expressive communication, and mathematical abilities. And science is hard. It takes practice, discipline, experience, and a level of intellectual maturity to successfully negotiate scientific thought processes. Understanding and taking advantage of the adventuring nature of teaching and learning science can strip away some of those mysterious and intimidating qualities. A participant in this study said, “You don’t have to be a particular type

of person to do science, or to enjoy science.” That statement may be true, however, science thinking and learning uses specialized cognitive processes that can be actively fostered in students by informed, creative, and adventuresome teaching. If, as Polloway and Patton (1993) stated, the three main dimensions of science learning and the associated cognitive skills are *information acquisition*: observation, listening, reading, study skills, directed experimentation; *information processing*: organization, analysis, classification; and *information integration*: synthesis, hypothesis, independent experimentation, generalization, evaluation; then the theory of adventuring is clearly relevant to the effective teaching of those skills.

Student success in science courses structured in nontraditional ways was examined (Allen, Tainter, Pires, & Hoekstra, 2001; Krupa, 2000; Reiss & Tunnicliffe, 1999; Wyckoff, 2001) and were noted in the NSF and AAAS studies mentioned above. There is consensus that a shift from lecture style dissemination to inquiry-based and experiential modalities, along with the incorporation of multi-sensory approaches may enhance scientific thinking skill development for students.

Although it is a cognitive tool of scientific discovery, linear thinking may be the hardest aspect of science literacy to teach students. Adolescent students are at the cognitive development stage where moving from concrete ideas about the way the world works and the very nature of science to the realization that science does not *create truth*. This is a stunningly difficult notion. Students must be able to hold contradictory statements of fact in their minds and, at the same time, draw on what they know to reach the logical conclusion expected by the teacher or the task. To teach the notion that science thinking tools include approaching the data from an altogether different angle—a creative, nonlinear, and perhaps a spiral approach, indeed a *mavericking* approach, would clearly benefit adolescent students.

Adventuring in the Classroom

The best science teaching methods rely on one-on-one attention. In classrooms observed for this study, laboratory periods were spent with the teacher directing each student in the way that that particular student received instruction. Teaching diagnostically was important, but the challenge to balance skill and content instruction, keeping student interest high and output rigorous, while also attending to the particular “science” cognitive tools could be overwhelming.

Teachers observed rose to this challenge in a number of highly creative and effective ways. Students were subjected to a variety of multimodal instruction. For instance, a final exam in an anatomy class included a scavenger hunt all over campus to collect bones to complete a human skeleton and answer specific concept questions. Alternative evaluation mechanisms such as multimedia presentations, posters, kinesthetic representations (via dance) as well as written papers to show mastery of the material were assigned. Chemistry laboratory experiences were inquiry based rather than “cookbook chem labs.” Students were taught to ask questions about chemical principles, then design their own activities to find the answers. Faculty also incorporated course worldwide web pages to facilitate communication; used computer-generated presentations for lectures; used computer compact disk programs, videos, and other assistive technology to enhance the multimodal presentations of material. Field trips and field research on campus were also widely used by science faculty. A variety of teaching modalities is essential when reaching adolescent students.

In addition to all the academic requirements of their time and energy, secondary and college students face the typical adolescent issues of identity, cognitive readiness for higher order thinking, parental expectations, stimulating environments away from home, availability of alcohol, drugs, and sex. Students may or may not be engaged in their own intellectual growth, no matter what they think their purpose is at school. Educators can tap into the evolutionary aspects of challenge and risk, and in so doing, provide a hook on which students may hang their learning. Adventuring is an effective model for a variety of teaching situations and is applicable to all learners.

By applying adventuring behaviors to everyday work, teachers and learners could enhance their experiences and deepen their thinking skills. It is easy to be critical of education today, but there is a world of information about how the brain works vis à vis development of reasoning and higher order cognition. Articles about creative ways to ensure engagement and inquiry about, in particular, scientific principles, are published regularly in teaching and research journals.

The National Science Foundation’s year-long review of postsecondary science, mathematics, engineering and technology (SME&T) teaching, published as *Shaping Our Future* in 1996, states that there were significant advancements in undergraduate teaching methods since the previous study (the Neal Report of 1986). However, much more

needs to be done to assure that United States students learn science and that teachers are prepared to teach SME&T. Recommendations from the 1996 NSF report include specific charges for higher education faculty, departments, administrators and accrediting agencies as well as local governments, industry, media, and nearly every echelon of our society up to the White House. The recommendations relevant to the current argument include:

SME&T faculty: Believe and affirm that every student can learn, and model good practices that increase learning; start with the student's experience, but have high expectations within a supportive climate; and build inquiry, a *sense of wonder and the excitement of discovery*, plus communication and teamwork, critical thinking, and life-long learning skills into learning experiences. (NSF, 1996, p. 3) (emphasis mine)

The NSF recommendations are all about adventuring. They are sound, sensible approaches to ensuring that pedagogy, praxis, data about how the brain works, and classroom experiences are linked for the best learning environments in science classrooms. There are ramifications to changing the way our nation educates students in science and how we train teachers to teach science. If we approach the adventure of science learning with all of our evolved cognitive tools and in a manner that honors exploration, mavericking, and skill acquisition and application, we could better serve the variety of learners in each classroom. Changing from lecture instruction to multimodal and experiential learning works. The use of a variety of instructional techniques is grounded in sound scientific research and reminds us that student success is at the heart of this debate.

Further Questions

Due to time constraints inherent in doctoral research, additional theoretical sampling is warranted. For instance, questions emergent from the study include:

- Do men and women adventure differently? Gender research clearly shows significant differences between men's and women's approaches to the world, both cognitive and behavioral (Belenky, Clinchy, Goldberger, & Tarule, 1986; Gilligan, 1982; Shepherd, 1993), and recent comments by Harvard University President Lawrence Summers (Bombardieri, 2005) questioning whether there is an "innate"

reason for the paucity of women in upper level science research begs to be completely and finally answered.

- What is the underlying neuro-chemistry that creates the behaviors of adventuring? Brain research is currently advancing rapidly and new information about how the brain works is appearing almost daily. How can these discoveries be used to understand and promote adventuring?
- What are some practical methods of encouraging adventuring in all classrooms? Curriculum design is important, but the training of teachers to be systems thinkers, gestalt oriented, and strong tool users is perhaps more vital to the long-term success of teaching and learning in our schools. Teacher education is important to encourage adventuring. What would a program for teachers include?

Conclusions

The theory of adventuring gives insights into how teachers and learners of science behave. Adventuring accounts for a variety of actions and thought processes found in the participants of this study. The next step is to answer the forgoing questions in relation to the dimensions and categories of adventuring, and create an education program that encourages adventuring in teaching and learning.

We use adventuring in our sophisticated, structured, systematic study of the unknown because we evolved from a newly bipedal, hairless, episodic-culture-based archaic *Homo* to the highly complex, sophisticated, and huge-brained *Homo sapiens sapiens* we are today. By tracing the evolution of the behavior, I offer the proposal that by understanding the origins of our brain/mind as an explanation of the adventuring behaviors we find in scientists today, we can better teach and learn scientific constructs so vital to our society, our planet, and our future. A citizen must not forfeit her right to engage in government because of ignorance. A citizen must be able to express his understanding of issues that impact his life.

Science is about questions: The natural world is mysterious. Nature is the ultimate “other”, and humans have evolved a great brain partly because of the big questions, the higher cognition required to discuss, interpret, and answer questions about the essential nature of Nature.

All the evolutionary adaptations we now enjoy were directly influenced by our environment: climate, landforms, vegetation, and fauna co-evolved. Scientists use their intellectual skills to attempt to understand and strip away mysteries, to get to the unifying principle. Long before Aristotle humans have wondered, experimented, thought deeply about results, and observed natural forces. We are a curious species.

Adventuring in science is ultimately about creating imaginary results and playing around with tests and materials until that result is realized. The classroom or lab is a playground for the creative, highly trained, passionate re-- searcher. Approaching teaching and learning from an adventuring context, as demonstrated by the scientists and learners researched for this study, would make the cognitive complexity of science accessible to all learners.

End Notes

⁵The amygdala is a small organ within the limbic system of the brain that is responsible for “fight or flight” decisions (Stefanacci, 2003).

² The area directly behind the eyes in the brain which is responsible for the processing of concepts such as time, sequencing and discrimination between two objects (Barkley, 1999).

³ In New England, school children take earth science, physics, environmental science, and biology introductory courses in middle school. Each class is revisited in high school as part of general education requirements.

⁴ At one time, two species of *Australopithecus* and two species of *Homo* existed simultaneously (Campbell, 1996).

Author

Katrina M. Maloney, M.Sc., Ed.D.
400 Old Chesham Road
Marlborough, NH 03455
603/876-4102
kmaloney@cheshire.net

References

- Allen, T.F.H., Tainter, J.A., Pires, J.C., & Hoekstra, T.W. (2001 June). Dragnet ecology--"Just the facts, Ma'am": The privilege of science in a postmodern world. *BioScience*, 51(6), 475--485.
- American Association for the Advancement of Science. (1991). *Benchmarks for scientific literacy*. Washington, DC: American Association for the Advancement of Science. Available at: <http://www.project2061.org/tools/benchol/bolintro.html> [10/14/99].
- Belenky, M.F., Clinchy, B.M., Goldberger, N.R., & Tarule, J.M. (1986). *Women's ways of knowing*. New York: Basic Books.
- Bertsch McGrayne, S. (1998). *Nobel prize women in science*. Secaucus, NJ: Carol.
- Bombardieri, M. (2005 Jan. 19). Harvard women's group rips Summers. *The Boston Globe*. Section A.
- Buss, D.M. (1999). Human nature and individual difference: The evolution of human personality. In L.A. Pervin & O.P. John (Eds.), *Handbook of personality: Theory and research* (2d ed.). New York: The Guilford Press.
- Byrnes, J.P. (1996). *Cognitive development and learning in instructional contexts*. Boston: Allyn & Bacon.
- Campbell, N.A. (1996). *Biology* (4th ed.). New York: Benjamin/Cummings.
- Donald, M. (1991). *Origins of the modern mind*. Cambridge, MA: Harvard University Press.
- Duncan, D., & Burns, K. (Producers). (1997). *Lewis and Clark*. [documentary film]. Florentine Films and Public Broadcasting Service.
- Fox Keller, E. (1983). *A feeling for the organism: The life and work of Barbara McClintock*. New York: W.H. Freeman.

The Grounded Theory Review (2005) vol. 4, no. 3

- Gilligan, C. (1982). *In a different voice: Psychological theory and women's development*. Cambridge, MA: Harvard University Press.
- Glaser, B.G. (1978). *Theoretical sensitivity*. Mill Valley, CA: The Sociology Press.
- Glaser, B.G. (1992). *Basics of grounded theory analysis*. Mill Valley, CA: The Sociology Press.
- Glaser, B.G., & Strauss, A. (1967). *The discovery of grounded theory*. New York: Aldine de Gruyter.
- Kent, M., & Coker, P. (1992). *Vegetation sampling and analysis*. New York: John Wiley & Sons.
- Krupa, J. (2000 October). The importance of naturalists as teachers and the use of natural history as a teaching tool. *The American Biology Teacher*, 62, 553-558.
- Kuhn, T.S. (1970). *The structure of scientific revolutions (2d ed.)*. Chicago: University of Chicago Press.
- Levine, M.D. (1987). *Developmental variation and learning disorders*. Cambridge, MA: Educators Publishing Service.
- Levy, J. (1978). *Play behavior*. New York: John Wiley & Sons.
- Milani, J. (Ed.). (1987). *Student study guide for biological science: An ecological approach (BSCS Green Version) (6th ed.)*. Dubuque, IA: Kendall/Hunt.
- Montgomery, S. (1991). *Walking with the great apes*. Boston: Houghton Mifflin.
- Morgan, E. (1972). *The descent of woman*. New York: Stein & Day.
- Morris, J. (2003). Finally, the top of the world. *Smithsonian*, 34 (2), pp. 54-63.
- National Science Foundation. (1996). *Shaping our future*. Washington, D.C: National Science Foundation. Available at: <http://www.her.nsf.gov/her/duo/documents/review/96139>

[1/20/02].

- Pollaway, E.A., & Patton, J.R. (1993). *Strategies for teaching learners with special needs*. Upper Saddle River, NJ: Prentice Hall.
- Reiss, M.J., & Tunnicliffe, S.D. (1999). Conceptual development. *Journal of Biological Education*, 34(1), 13-16.
- Sayre, A. (1975). *Rosalind Franklin and DNA*. New York: W.W. Norton.
- Shepherd, L.J. (1993). *Lifting the veil: The feminine face of science*. Boston: Shambhala.
- Simmons, O., & Gregory, T.A. (2003, Sept.). Grounded Action: Achieving optimal and sustainable change. [51 paragraphs]. Forum Qualitative Sozialforschung/Forum: Qualitative Social Research. [on line journal], 4 (3). Available at: http://www.qualitative-research.net/fqs_texte/3-03/3-03simmonsgregory-e.htm. [9/25/03].
- Sonnert, G., & Holton, G. (1995). *Who succeeds in science? The gender dimension*. New Brunswick, NJ: Rutgers University Press.
- Stefanacci, L. 2003. Amygdala, Primate [world wide web]. Massachusetts Institute of Technology. Available at: <http://80cognet.mit.edu.cardinal.fielding.edu/MITECS/Articles/stefanacci.html>. [7/23/03].
- Wilson, E.O. (1992). *The diversity of life*. New York: Norton.
- Wyckoff, S. (2001). Changing the culture of undergraduate science teaching. *Journal of College Science Teaching*, 30(5), 306-312.