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How High School Science-related Experiences Influenced Career Persistence

Andrew Dwight Shaw
University of Missouri-St. Louis, ashaw@wcastl.org

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HOW HIGH SCHOOL SCIENCE-RELATED EXPERIENCES INFLUENCED SCIENCE CAREER PERSISTENCE

A Thesis

Submitted to the faculty

of

University of Missouri – St. Louis

by

Andrew D. Shaw

In Partial fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

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DEDICATION

This dissertation is dedicated to my parents, Gordon and Jean Shaw. While interviewing the scientists for this research, it occurred to me that my own entrance into science was remarkably similar to theirs. For as long as I can recall, my folks took my siblings and me on trips to museums and parks. We enjoyed stimulating and fervent conversations about numerous issues around the dinner table, and we were regularly supported in our school work. Books were important, and my mother read to us every night.

My first science fair project was a robot, constructed out of erector sets. My father was an invaluable consultant, advising me that the triangle is the sturdiest structural component. Later, he helped me build an FM radio from a kit. My brother (who is now a chemist) and I made lead soldiers with a casting set, and disappearing ink with a chemistry set. My insect collection had over 200 insects – five times what was required. Like so many scientists, I had a parent with a science background – my father was an electrical engineer from MIT.

I still remember Mr. Manion in 6th grade and my introduction to chemistry. "Hands-on" was such a radical idea that we were only allowed to mix baking soda and vinegar after school, shooting corks off of test tubes. Mr. Nieman in 8th grade made us write papers on each of the systems of the body, and showed us cool movies sponsored by Bell Telephone. In 10th grade Biology, Mr. Robards required us to make an insect collection, and to this day I enjoy studying them and can recall their taxonomy. They loved science, and it was contagious.

Though I may not recall when I decided to pursue a career in science education, I do not recall ever considering anything else. My parents created a rich and nurturing environment in which to grow up and explore. I only hope that my students feel the same way about my classroom. Thank you, again, Mom and Dad! I have been blessed by parents who faithfully instilled in me a love for the Creator, and for His Creation!

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My advisor, Dr. William C. Kyle, and the rest of my committee - Dr. Gary S. Groenewald, Dr. Joseph L. Polman, and Dr. Pat Somers. You have been patient, thoughtful, and constructive in your balanced encouragement and reflective analysis of my research and writing.

The thirty-two scientists who graciously and enthusiastically gave me their time, reflections, and insights in the midst of their busy schedules. Thank you for caring about the "big" picture – enhancing and furthering science and science education in this country and abroad. Especially, I would like to thank Dr. Gary Groenewald, Mr. Tony Appelhans, and their team who made my twelve summers at the INL so incredible and rich. I grew professionally, learned an incredible amount about science and doing science, and made life-long friends.

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Pamela Shaw, my wonderful wife, who has not merely tolerated living with a busy and sometimes stoic teacher and scientist for over thirty years, but loved me, prayed for me, and encouraged me. You are what Proverbs 31:10-31 is all about!

Melissa, Matthew and Rachel, Mark, and Michael Shaw who have been a joy to their father, and a blessing to their parents. You have always understood and supported me in my calling.

The Lord, from whom all these blessings flowed. Great is your faithfulness.

> For by him [Christ] all things were created: things in heaven and on earth, visible and invisible, whether thrones or powers or rulers or authorities; all things were created by him and for him. He is before all things, and in him all things hold together. (Colossians 1:16)

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ABSTRACT

Shaw, Andrew D., Ph.D., University of Missouri – St. Louis, 2005. How High School Science-related Experiences Influenced Science Career Persistence. Major Professors: William C. Kyle, Jr., Ph.D., Gary S. Groenewald, Ph.D., Joseph L. Polman, Ph.D., Pat Somers, Ph.D.

The events of 9/11 brought into focus two ongoing trends that were present before this tragedy and have continued since: 1) The United States needs more scientists if it is to ensure its freedoms and maintain its economy. 2) The number of scientists in the "pipeline" is declining because of the diminished presence of foreign scientists (they are wanted in their own countries), the under-representation of minorities and women, and the reduced numbers of students able and willing to take on the scholastic rigors necessary for a science or engineering degree.

Though much has been written about improving science education, and numerous projects have been conducted to promote it, few education researchers have questioned the scientists themselves about the experiences, practices, and people that positively influenced them, particularly during their pre-college years. Towards this end, thirty-two scientists were interviewed in order to address four research questions: 1) How did practicing scientists' personal relationships with their science teachers influence their decision to pursue a career in science? 2) What pedagogical methods (e.g. lectures, demonstrations, "hands-on" work, problem solving, small groups) used in their high school science courses, if any, played a significant role in propelling certain students towards a career as a practicing scientist? 3) What high school science-related support structures (e.g. labs, equipment, textbooks, technology), if any, played a significant role in propelling certain students towards a career as a practicing scientist? 4) What high school science-related educational activities (e.g. science fairs, clubs, summer internships), if any, played a significant role in propelling certain students towards a career as a practicing scientist?

Some of the scientists reported that they knew they were headed towards a career in science before they even entered high school, while others did not make a decision about a science career until after they had graduated from college. The prevailing conviction, however, was that the encouragement from others (though not exclusively by teachers), the excellence of teaching (regardless of pedagogical style), and the richness of science related experiences were the most influential factors in either maintaining or initiating a persistence in science towards a career.

CHAPTER 1

Introduction

A little more than half a century ago the 33rd President of the United States, Harry S. Truman, signed into law the National Science Act of 1950 (Public Law 81-507). This legislation created the National Science Foundation (NSF) and gave it the mandate “to promote the progress of science; to advance the national health, prosperity, and welfare; and of other purposes.” Though this event may have seemed inconspicuous at the time, it was sandwiched between two historic developments that would forever change the relationship between science and government. During the previous decade the atomic bomb had been unleashed on Hiroshima and Nagasaki (1945), effectively ending World War II. In the ensuing decade the U.S.S.R. would be the first to launch into space with Sputnik (1957), signaling the beginning of a “Cold War” contested both through diplomatic venues and in scientific laboratories.

These two watershed events helped shape the concerns and initiatives that have defined the United States’ scientific and technological endeavors to this day. Such “enduring themes” include (a) the support and performance of research and development and the role of the federal government in that support; (b) the centrality of human resources for science and engineering and the critical component of educating those scientists and engineers; (c) the realization that research and development are key to economic growth; and (d) the cultivation of international cooperation in science and technology (National Science Board, 2000).

Every one of these areas of concern involves science education, whether it is the training of the next generation of researchers or creating an informed and knowledgeable public. In fact, recent landmark events such as the decoding of the human genome and, in the same year, the attacks on the World Trade Center in New York City on September 11, 2001, only reinforce the critical part that science education must play in the scientific and technological efforts to promote human health and prosperity and preserve our freedom.

Background

Recently (October 5, 2004), the then Secretary of the United States Department of Education, Ron Paige, addressed a meeting of the Institutions of Higher Education Science and Mathematics. He stated,

> We live in a world that is the product of scientific creativity and discovery… the scientist and the mathematician engage in some of the most exciting work available, and all of us benefit from the progress of science… No work could be more important. That is why it is vital to examine the way we produce our scientists and mathematicians. Their lifelong efforts will shape and determine our future. So we must give special attention to their training. (p. 1)

Few in the scientific community or otherwise would challenge his claim. “Since 1980, the number of nonacademic science and engineering (S&E) jobs has grown at more than four times the rate of the U.S. labor force as a whole. Nonacademic S&E jobs increased by 159 percent between 1980 and 2000” (National Science Board, 2004, p. 3-3). This figure is augmented by the fact that “even among S&E bachelor’s degree holders working in non-S&E occupations, more than two-thirds reported that their job related to their field of degree” (National Science Board, 2004, p. 3-3).

At the same conference on the same day, Ted Simmons, President of the Education Commission of the States, concurred, but added an ominous note:

> America’s competitive edge in the global economy, the strength and versatility of its labor force, its capacity to nourish research and innovation – all are increasingly

> dependent on an education system capable of producing a steady supply of young people well prepared in science and mathematics. But all along the pipeline – from the quality of science and mathematics instruction in the early grades, to the performance of our high school seniors on international tests, to the content and rigor of teacher-education programs in our colleges and universities – there are troubling weaknesses, gaps and disconnects. (p. 3)

If this concern sounds familiar, it is because such predictions have been a recurring theme since the seminal study, *A Nation at Risk,* first sounded the alarm back in April, 1983. The Third International Mathematics and Science Study (TIMSS), in 1995, and the National Assessment of Educational Progress (NAEP, the "Nation's Report Card"), in 1996, have not only corroborated the initial assessment but broadened the scope. More recently (2000) former astronaut John Glenn chaired a committee that produced *Before It's Too Late: A Report to the Nation from the National Commission on Mathematics and Science Teaching for the 21st Century*. The first four words of its title say it all – the problem continues, and its amelioration is crucial.

Despite science education's essential role, the statistical indicators regarding the effectiveness of undergraduate science education are disappointing. As reported by Michael L. Peralta, the executive director of the Junior Engineering Technical Society, Inc. to the Committee on Science of the United States House of Representatives:

> Unfortunately, the number of graduating high school students each year who are *capable* (courses, grades, etc.) of entering university study leading to careers in engineering, mathematics, science, medicine, and math or science teaching is only 12% of the overall high school senior population and only 6% of the senior-level minority population. (1998, p. 2, italics added)

As low as these percentages are, they are effectively reduced because not all of these students will pursue a career in a science-related field. This situation is compounded by the forecast that Peralta describes further:

> Currently, more than half of new jobs require some form of technical literacy, but by the year 2000, approximately 60% of new jobs will require skills possessed by only 22% of high school graduates and dropouts entering the labor market today. (1998, p. 2)

Six years later the situation had not improved. Doctorates in science and engineering were down by 6.5% between 1998 and 2001, and the decline appears to be systemic (Fogg, 2002). Furthermore, since more than half of them are over 40, “the total number of retirements among S&E-degreed workers will increase dramatically over the next 20 years” (National Science Board, 2004, p. 3-3). Sanders (2004) adds to this concern in his report at a recent national conference on teacher preparation:

> Over the past two decades… the U.S. science, engineering and technology workforce has grown at more than four times the rate of total employment, in large part because of our ability to integrate large numbers of foreign-born scientists and engineers into the workforce. But in the global marketplace, competition for these workers is steadily widening and intensifying. At the same time, the proportion of U.S. citizens qualified to fill science and engineering jobs is stagnating. The number of young people preparing for careers in these fields has steeply declined, and a large portion of the current workforce is rapidly approaching retirement age. (p. 3)

In the past this deficit was filled by hiring foreign-born (and often educated) scientists. For example, in 1996 “more than one-fourth (28%) of the doctoral-level scientists and engineers doing R&D [research and development] in the United States are foreign-born” (Frontiers, 1996, p.1). Since 9/11, however, this percentage has dropped precipitously by 20.1%, and the number of foreign students studying in this country to become scientists and engineers fell 27 % (National Science Board, 2004, chap. 3, p. 37). In addition, the number of work visas available has declined.

Another reason for the decline in the number of foreign-born scientists and engineers is by contrast a positive one. This is because "superb science is being carried out in many countries; second, the scientific enterprise has become truly global in character (Leshner, 2004, p. 197). Alan Leshner, the Chief Executive officer of the American Association for the Advancement of Science, continues in his editorial by saying, "This globalization of science is cause for celebration. Better still, more countries are making productive investments in their science infrastructures, and this portends well for the future of all humankind" (p.197).

There is one untapped resource, as Paige (2004) points out:

> Too many of our students are not well-educated in these subjects [science and math]. American students lag behind students in other developed countries. And many of our minority and disadvantaged students receive an appallingly poor education in these areas. This is one reason why there is a serious shortfall of all students, and especially minority students, entering college in the hard sciences or applying to graduate school. It is a major reason for the low numbers of minority students entering engineering or medicine. And this problem represents a serious underutilization of the vast talent available, of the promising contributions that could be made by these students. And that's why we must address this problem with candor, urgency, and vision. (p. 1)

This under-representation had already been reported but now takes on added significance:

> Expanding the pool of scientists and engineers has been a persistent problem for educators and employers alike. Between 1998 and 2008, jobs in science, mathematics and engineering (SME) fields are expected to increase four times the rate of all other employment opportunities in the United States. This translates into a demand for 1.9 million more trained professionals in these areas (National Science Board, 2000). Presently, White and Asian Americans constitute 82.3% and 10.4 % of the SME workforce, respectively while African Americans, American Indians, and Chicanos/Latinos remain underrepresented in these growing careers relative to their representation in the U.S. population – at 3.4%, 0.3%, and 3.1%, respectively. (Bonous-Hammarth, 2001, p. 92)

Almost 20 years ago, in a nearly prophetic fashion, Simpson and Oliver (1985) predicted:

> Science courses commonly taught to adolescent students in most school systems do not produce individuals with positive attitudes toward science and do not produce students eager to continue taking science courses in high school and college… If this trend is not altered, the United States stands to lose its prominent position as a world leader in science and technology. If this happens, the past influence our country has displayed as a major force in the world will be diminished. (p. 523)

Coming full circle, who will teach these science courses, and what happens if they cannot do it well? According to Paige,

> Without teachers who are well-prepared in mathematics and science in our elementary and middle schools, you will have fewer and fewer students entering high school prepared for higher-level mathematics and science courses. And that translates into even fewer American students coming to your universities to major in mathematics, science,

> engineering or technology. Our nation cannot remain the leader in innovation and productivity by depending on foreign students who may return to their home countries. Our national defense cannot stay strong without American scientists and engineers taking the places of our Sputnik-era leaders who are looking at retirement in the next five years. (2004, p. 2)

Problem

Obviously, there is a gap that science education needs to address, and much has been written about how to fill the void. Indeed, the literature is filled with phrases such as “hands-on,” “discovery oriented,” “less-is-more,” “laboratory approach,” “demonstrations,” “project-based,” “inquiry learning,” and “problem-based.” However, little has been done to ascertain from practicing scientists what experiences in their *own* schooling have had a significant impact in their choice of a career. What teaching styles, what curricular materials, what pedagogical approaches, and what practices and activities encouraged *them* (or hindered them) in their dreams of becoming scientists?

Research Questions

In interviewing practicing scientists about their high school science-related experiences, the researcher concentrated on the following research questions:

1. How did practicing scientists’ personal relationships with their science teachers influence their decision to pursue a career in science?
2. What pedagogical methods (e.g., lectures, demonstrations, “hands-on” work, problem solving, small groups) used in their high school science courses, if any, played a significant role in propelling certain students towards a career as a practicing scientist? In

other words, did particular pedagogical methods positively influence the decisions of high school students to become scientists?

3. What high school science-related support structures (e.g., labs, equipment, textbooks, technology), if any, played a significant role in propelling certain students towards a career as a practicing scientist? In other words, did certain facilities or materials positively influence the decisions of high school students to become scientists?
4. What high school science-related educational activities (e.g., science fairs, clubs, summer internships), if any, played a significant role in propelling certain students towards a career as a practicing scientist? In other words, did certain co-curricular or extracurricular opportunities positively influence the decisions of high school students to become scientists?

Data from the interviews might also provide insight, at least tangentially, into the following secondary questions:

1. Did women or minorities encounter significant support structures or, conversely, obstacles in their science-related experiences that affected their pursuit of science as a career?
2. Did access to technology (e.g., audio-visuals, computers, Internet, graphing calculators, electronic data-gathering devices) – technology that was more readily available to younger scientists when they were in high school than to older ones – significantly influence certain students in their pursuit of science as a career?

Purpose of the Study

The purpose of this study is to investigate how high school science-related experiences influenced some practicing scientists to persist in their career. This investigation may shed light on those practices and experiences that influenced or impeded their pursuit of a career in science. Finally, it is hoped that some insight will be gained into whether or not there are any pedagogical practices in high school science classes that influence or deter women and minorities from seeking a career in science.

Towards this end, 32 practicing scientists were interviewed and surveyed about their experiences relative to science, especially as it related to their formal high school education, in order to examine what experiences influenced them in their choice of a career in science.

Brief Literature Review

As might be expected in a society and culture that is eminently concerned about education and technology, the intersections between education and the practice of science are many. A multitude of permutations may move scientists into classrooms or students into laboratories at many different levels of education and for different lengths of time. This literature search will be confined to the more specific topic of the relationship between *high school* science and practicing scientists.

Even within these confines numerous possible combinations exist. Programs abound which provide science-related experiences for high school students. Some of them are held during the summer, and some are ongoing collaborations. Some are competitions, some the result of science fair projects, and some are field trips to nearby labs. Many programs bring scientists into the classroom as special speakers (short term) or as permanent teachers (long term). This literature search, however, will concentrate on discovering what high school science *teacher practices and methodologies and associated experiences* propel a student to become a practicing scientist.

Many educational practices, methodologies, and experiences have been reported which make science fun, interesting, and relevant. These include “inquiry based learning” approaches, authentic problem solving, open-ended labs, demonstrations, and various collaborative and cooperative strategies, to name just a few. In addition, much has been written about high school student attitudes towards science and their willingness to pursue a career in science. But just because a student is interested in science or does well in it does not necessarily mean that she/he will pursue a career in science. So, to further focus this study, *only what scientists themselves say* about their high school science teacher practices and methodologies and associated experiences will be investigated, and not what educators, researchers, or the students themselves relate.

When all of this whittling down is done and the investigation homes in on the sole task of discovering what practicing scientists themselves say about their high school science education, the literature is inexplicably silent. Considering the previously mentioned need for scientists, and especially the critical problems (that have a scientific component in their solution) which we face as a nation and a world, it is remarkable that so little has been done to determine “from the horse’s mouth” -- the scientists themselves -- what high school educational practices, methodologies, and experiences influenced their personal decisions to become scientists.

A single study (Rowsey, 1997) was found that asked 35 scientists a series of questions about why they chose science as a career. The questions probed, among other things, whether or not certain individuals, experiences, or events influenced them in their career choice. Forty-three percent said that at least one high school science teacher had influenced them, 22% reported that an experience had made a difference, and 37% said they had been positively influenced by an historical event. Its scant 11 references were from 1953-1991.

In one of the few other articles that reported the sentiments of scientists about science education, the results of a survey of 2500 members of the American Association for the Advancement of Science sponsored by the Pittsburgh-based Bayer Corporation and conducted by Roper Starch Worldwide were given:

> On average, the scientists—1435 Ph.D. holders who are members of the American Association for the Advancement of Science—gave the quality of science education only average grades: a C-minus for elementary school and a C for high school. (Lawton, 1998, p. 1)

Whether this assessment was about their own science education or their perception of science education today was not spelled out, though the latter seems more likely. Nevertheless, and more to the point of this research, the study's participants did make several pertinent observations that seemed to seek a middle ground between traditional and modern approaches to teaching science. For example, many of those polled "would also like to see a continuation of some traditional methods of teaching and learning, particularly for high school science" (p.1).

Yet 70% felt that the curricula should have a significant amount of "teachers acting as guides and mentors instead of lecturing; students carrying out experiments and formulating their own results; and students thinking critically, testing assumptions, and questioning common opinion" (p. 1). This polarity was further reinforced by the following statistic: "But even as 75 percent of scientists said they would like to see 'a lot' of teachers acting as guides for high school students, 61 percent said they'd like to see 'a lot' of lectures by teachers covering major topics" (p. 1).

An editorial by Gail Richmond, also in 1998, for the *Journal of Research in Science Teaching*, began promisingly:

> What experiences contribute to the overall development and preparation of a scientist: Are there elements of this process that educators can recreate to support the development by all students such that they acquire similar skills and habits of mind, regardless of the career path they finally select? And if so, what shape might these processes take in science classrooms? (p. 583)

Unfortunately (in terms of this research), the article focused on the inclusiveness of science education for all, the importance of the professional community in fostering the development of the future scientist, and those *graduate* school experiences that should help to shape and prepare the budding scientist.

In a more recent longitudinal study involving 85 winners of the Intel-Westinghouse Science Talent Search, several researchers investigated the variables that led to the continued pursuit of a career in science. Results revealed that family differences, other interests, and the lack of grant money or academic openings often resulted in attrition. The influence of mentors was a positive indicator, but little else relating directly to their high school science experience was presented (Subotnik, Stone, & Steiner, 2001).

Finally, in a survey of his students conducted by college chemistry professor Christopher Bauer (2002), 72% responded (N = 130) when he asked them at the end of their first year of college chemistry about their high school chemistry experiences. Even though they were not practicing scientists, per this study, and some of them will in all probability not pursue careers in science, their responses may be similar. Teacher behaviors that correlate with positive student attitudes include: “(a) teacher enthusiasm, (b) ability to explain and to motivate, (c) knowledge of chemistry, (d) caring attitude, (e) student enjoyment and interest, and (f) challenging and rich instruction with experiment and demonstrations” (p. 53).

Method

The research design for this study consisted of two parts: (1) interviews, and (2) a survey of selected autobiographies. The primary data came from personal interviews with 32 practicing scientists located in the St. Louis metropolitan area (MO), where the researcher lives and teaches, and in Idaho Falls, Idaho, where the researcher travels each summer to engage in surface chemistry research at the Idaho National Engineering Lab (INEL). The INEL, soon to be called the INL, is one of the laboratories operated by the United States Department of Energy.

The scientists who participated in the interview process were selected because they had previously shown an interest in high school science education either through personal conversation or through recommendation by another scientist. Each scientist was then contacted personally, by phone, or by email, and an appointment was made at the mutual convenience of the scientist and the researcher.

Prior to the interview, each scientist was provided a questionnaire requesting demographic data (e.g., age, field of research, size and kind of high school attended, science courses taken in high school) and given some general questions to initiate recall and reflection. These questions, amplified in Appendix A, were

1. Describe your high school science experience.
2. To what extent did your high school science experience influence your decision to pursue a career in science?
3. If you were to teach science in high school, how would you do it?

Each interview lasted about thirty minutes to an hour, during which time the scientist was asked the three questions stated above as well as the other questions found in Appendix A. The interview allowed for follow-up questions, based upon the scientists' responses, in order to probe those responses and focus on potential areas of special interest, especially as it related to the pedagogical approaches of their high school science teachers and their personal science-education experiences during that same period of time. All the interviews were taped and transcribed.

The secondary data, for the purpose of corroboration (triangulation), came from multiple sources that were primarily autobiographical. They included (1) a book *The Making of a Scientist* (Roe, 1952) containing the analysis of interviews with scientists; (2) a book *Curious Minds* (Brockman, 2004) containing a compilation of essays by scientists about how they became scientists; (3) several manuscripts about the lives of Science Nobel Prize winners; and (4) an online database (oral archive) containing the personal accounts of women in science.

Assumptions and Limitations

There are, no doubt, many ingredients in the decision of an individual to pursue a career in science. As Woolnough and Guo (1997) have observed,

> Different students are encouraged towards scientific and technological careers by different influencing factors. There is no simple answer to the question about what must be done to encourage more students into science, for the same factor will be more influential on some students than on others. (p. 111)

Of course, some of these factors have nothing to do with students' formal education, such as a natural ability, an early childhood visit to a museum or science center, or a parent or other admired adult who was a scientist. Hopefully, though, experiences before and after high school *did* play an influential role in the scientist's decision. However, this study primarily considered only the science-related experiences that occurred during the high school years.

Conversely, there are also many factors that deter an individual from pursuing a career in science. Such impediments are not always the fault of the high school science teacher. As is true in any discipline, the teacher can be limited by an established curriculum that is too weak, an administration that is not supportive, a community that does not make education a priority, or any of the myriad of other variables outside the control of the teacher. However, to the degree that the teacher has control over what is taught in the classroom, and how it is taught, this study seeks to identify those effective practices.

As is apparent in the introduction and background to this dissertation, the immediate context and basis for this research is set in the United States. The statistics result from studies of the U.S. scientific and engineering workforce, and the quotes are of U.S. government, academic, and business officials. In addition, the vast majority of the literature references cited in Chapter Two have an American focus, and the scientists who were interviewed are U.S. citizens. However, neither teaching or learning, nor science or research, are exclusive enterprises of the U.S., but human ones that transcend nationalities and cultures. Just as the educational and scientific practices and experiences of other nations can inform (and, indeed, have informed) those of the U.S., so it is hoped that this research can reciprocate.

Further assumptions and limitations specific to this study include, (a) those factors which help future scientists to persist are often the same factors which will help any student persist in their chosen career, e.g., good teaching or mentoring; (b) the opposite of negative factors (or their removal) is often assumed to be positive factors, e.g., elimination of gender and racial bias; (c) factors identified by studies from other countries apply in this country, and vice versa; (d) many of the factors, such as summer research experiences, shown by the literature to help minorities and women to persist in science will probably help any student; (e) no structured effort will be made to discern if the scientists being interviewed are successful or not-so-successful. Though their stories may be different, their perspectives can nevertheless be pertinent and informative.

Finally, the central goal of science education is not, nor should it ever be, to exclusively prepare students to become scientists (Hurd, 1998). In fact, "an emphasis on an education which favors only one section of society to the detriment of others, in this case those who might potentially become an academic elite as scientists or engineers, would not be widely acceptable" (p. 114). Besides, many, if not most, students have greater talents and gifts in other disciplines, such as writing, music, art, and business. But all of these students must have some knowledge about science and its processes if they are to be informed citizens and productive members of our technological and rapidly changing society. To that end, a good science education must meet the needs of a broader clientele than just future scientists. Ideally, within the context of this greater purpose, the scientists of tomorrow are not merely unhindered in their scientific aspirations but effectively nurtured in them as well.

If this were a quantitative study, the conclusions would depend upon the accuracy and truthfulness of the responses, as is the case in any research involving self-reporting by participants in the study. Certainly, the older the scientist, the more time has transpired since she/he was in high school, and complete recall may be difficult. However, since no names of teachers or high schools were gathered, there would be little reason for a scientist to fabricate responses. It is hoped that since scientists are in the business of accurately describing various aspects of the universe they would be naturally dedicated to the accuracy of their own responses. Of course, in any retrospective account of a scientist's experiences, the meaning that he/she ascribes to those experience(s) in high school today might very well be different than the meaning (if any) that he/she ascribed to it back then. Certainly this speaks to the value of longitudinal studies.

Again, if this were a quantitative study, several criticisms would apply. First, since the scientists being interviewed were principally located in communities to which the researcher had convenient access, it is possible that they do not represent a true cross-section of scientists and thus represent a problem to external validity. Secondly, this threat to sampling is potentially aggravated by the small number of scientists that could be reasonably interviewed. Finally, those scientists who agreed to participate in the study also might not represent a true cross-section of scientists. The fact that they *chose* to participate might be an indication of some inherent difference between them and the population of scientists at large. However, because this is a qualitative study, these criticisms become academic since the principal goal is not to ascertain generalizability of data but to offer rich interpretation of varied experiences of a broad spectrum of scientists.

Scope and Delimitations

Scientists, it is reasonably assumed, have college and graduate degrees in some field of science. Beginning as early as their freshman year in college, they take many courses in various disciplines of science, gradually narrowing in on their chosen specialty as they progress. Post-baccalaureate study and research experiences are even more sharply focused. However, their early success in college often depends on how adequately their high school prepared them in science. Students all too frequently drop their science major shortly after entering college. Others, upon exposure to other disciplines, such as music and art, that they may not have had the opportunity to experience in high school, may decide to pursue other career pathways. However, too many were either not adequately prepared for the workload or did not have an adequate background in their previous educational setting (high school). Consequently, it was deemed appropriate that scientists be queried about their high school science experience.

The next reason for asking scientists about their high school science education and experiences is because this is one way (of many) to evaluate the success or failure of the continuous science education reforms that have been initiated during the last several decades. Certainly the reforms have other goals, such as promoting a scientifically literate populace and getting students to enjoy science. But in the domain of science and its practice, whether or not these reforms have increased and improved the body of scientists is an important measuring stick. Parenthetically, even though some of the reforms have as a goal the promotion of national prosperity and defense, this research only explores early (pre-college) formative factors such as relationships with mentors and internships. As such, this study is located in the educational policy and not the economic or defense policy of the United States.

A third reason for this study is based on the realization that even though we live in an increasingly scientifically based and technologically oriented society, the most recent employment data indicate two alarming trends, both of which have already been mentioned. The first trend is that a large number of foreign scientists must be recruited to fill science/research vacancies in the United States. Though some of these positions are filled with visiting scientists specifically for the important purposes of cross-cultural exchange, many are the result of a shortage of qualified American scientists. Exacerbating this challenge is the fact that since 9/11 it has become increasingly difficult for foreign scientists to enter the United States.

The other "trend" is really an ongoing problem. Women (especially in the physical sciences) and minorities in general are underrepresented in the scientific ranks. Despite heavy recruiting and significant scholarship opportunities, only marginal progress has been made in the realm of attracting women and minorities to scientific and technological careers. The causes of this minimal presence are no doubt numerous, complicated, and interconnected and so it is hoped that this study will shed some light on any high school science education components of this difficult issue. Towards this end, women and minority scientists will represent a larger proportion of the sample population (28.1% and 21.9%, respectively) than they do in the scientific community at large.

The last reason high school science-related experiences were chosen to be the topic of questions posed to scientists is due to the fact that the researcher is himself a high school science teacher as well as a practicing scientist, albeit in the latter role part time during the summer. The responses by scientists to questions about high school science teachers strike close to home on both accounts!

Teaching, like learning, is not formulaic but highly individual and contextual. Even though the background knowledge requested from scientists was quantitative, the sought-after information regarding their high school science experiences was inherently qualitative because no two scientists could possibly have identical experiences in high school or be exposed to exactly the same kind of teaching styles. If two teachers were able to teach with the same philosophy and methodology, their personal differences, unique circumstances and backgrounds, and distinctive personalities would naturally result in very different classroom environments.

The teachers and teaching would be different, but so would the learning, since no two students are the same either. This being the case, a qualitative study was deemed most appropriate in order to truly capture the rich yet subtle influences that helped to shape high school students into mature scientists. This qualitative study was phenomenological in nature, searching for those ingredients in a high school science education that mold scientists even at a young age.

Definition of Terms

Practicing scientists are defined for the purposes of this study as those who have engaged in scientific research for a minimum of five consecutive years during any time after their completion of a postgraduate degree (Masters, Ph.D.) in a physical, earth, materials, or biological science. The research may have been conducted under the auspices of a government agency (e.g., U. S. Department of Energy, Missouri Conservation Department), an educational institution (e.g., University of Missouri at St. Louis) or a private corporation (e.g., Monsanto, Sigma Chemical, Boeing). Social scientists (e.g., educators, psychologists, sociologists, political scientists) were not interviewed since their contribution to developing science and technology is not as direct.

Scientific research is defined for the purpose of this study as any endeavor in the physical, earth, materials, or biological (the so-called "hard" sciences) that promotes the ongoing understanding and discovery of the laws and principles that govern the operation of the *physical* universe. The research must include experimentation and the gathering of data. The design and construction of tools and apparatus to facilitate this investigation as well as the writing of computer software to gather, analyze, and represent the resulting data is included. Again, psychological and behavioral research will not be included.

High school science education is defined as those foundational science courses (Physics, Chemistry, Biology) taken during grades 9-12, as well as any science electives such as Astronomy, Environmental Science, Electronics, Human Anatomy and Physiology. It is understood that, on occasion, a mathematics course may also have had a significant impact in the education of a scientist or a science course taken during middle school. The education may be from a public, private, parochial, or home school.

Science-related experiences incorporate teaching styles (e.g., lectures, discovery or inquiry based, problem solving, demonstrations, "hands-on"), laboratory experiences (including formal write-ups, open-ended, original research, lab manual, computer based labs, simulations), co-curricular and extracurricular experiences (e.g., science fairs, science clubs, summer internships), technology (including textbooks, internet and web-site use, videodisks, overhead projections, videocassettes, film, and filmstrips), and the relationships which the scientists had with individual teachers or mentors.

In addition, there are many science-related experiences that are not necessarily associated with formal education or school. These include family visits to museums and national parks, discussions of science issues with family and friends, playing with science-oriented "toys" (e.g., model rocketry, chemistry sets, microscopes, erector sets), reading science-related books, enjoying science-related hobbies (e.g., collecting insects, building radios), and viewing science programs on TV or at the movies.

CHAPTER 2

Review of Literature

Introduction

In an imperfect world filled with finite and imperfect people, every human activity, endeavor, and idea can be improved. This has resulted in a myriad of programs, remediations, and interventions designed to ameliorate whatever deficiencies, side effects, or inadequacies may have resulted in order to enhance them. In order to evaluate the long-term effectiveness and consequences of many of these programs and interventions, studies that assess persistence are often employed. Because of the plethora of studies in the literature that relate to education and subsequent careers, this review will be limited to those that focus particularly on the factors that influence students to pursue a career in science.

After a general overview of *non*-school-related influences and those school-related influences that transpired before middle school, those studies that address the more narrow focus of middle and high school science-related experiences will be reviewed. Particular emphasis will be given to what scientists themselves report were the high school science-related experiences that influenced them.

Numerous studies report the under-representation of minorities and women in the sciences, how various special programs and initiatives might offset this deficiency, and the factors that positively influenced the career persistence of some. These reviews will generally be dispersed throughout this chapter under various headings rather than grouped together in a separate section. The reason for this is the assumption that at least some of the factors and influences that are identified as promoting inclusion of minorities and women in the sciences would also help anyone to persist in science, regardless of race or gender.

Non- School-related Influences

Ask a dozen scientists what influenced them the most to pursue a career in science and there could very well be a dozen answers. These answers would run the gamut from “I wanted to become a scientist for as long as I can remember” to “I didn’t really decide until halfway through college.” For some, high school was a significant turning point in their career decision-making process, and for others it was quite unremarkable. Therefore, in order to provide a context and give voice to those factors over which teachers at any level have little or no part of, a hierarchy of individual-to family-to societal is given.

Individual

This category heading (and a subsequent one – *social*) encompasses influences that arise from the individual her/himself and comes from a report prepared by Byrne (2000) for the Science Council of British Columbia and Science World. After an exhaustive review of 1,500 pertinent studies, he enumerated several factors that influenced children’s attitudes towards science and technology. These factors, which will serve as the rubric for this part of the review, are grounded in sociological theory: (1) age and educational level, (2) stereotypes and misconceptions, (3) gender, (4) self-concept, (5) ethnicity, and (6) socioeconomic status (SES) (Byrne, 2000).

At what age does a student choose a career? This complex and dynamic process takes place as a child matures. Byrne (2000) refers to studies that show that the process begins as early as age five and that by the time high school is finished, about two-thirds of the students have made a preliminary career choice. During this time, students move from choosing a career based upon social validation to eliminating occupations incompatible with personal interests and abilities.

Obviously age and education cannot be extricated from the other five factors (stereotypes and misconceptions, gender, self-concept, ethnicity, and SES) identified by Byrne. However, his literature review did point out that “career plans related to science and technology start crystallizing by age fourteen” (p. 3), but that a larger trend of increasingly negative attitudes toward science may begin as early as second grade according to one study, or sixth and seventh grade according to another (p. 3).

Sometimes the lack of persistence to a career in the sciences is less the product of an absent positive factor as it is the existence of a negative factor. Such is the case with stereotypes and misconceptions. For whatever interconnected reasons dealt with elsewhere in this chapter, according to Byrne, these confusions can be subdivided into those that generate a false image of the scientist, those arising from a misperception of the nature of scientific work (e.g., it is difficult, requires sacrifice), and those that perpetuate a gender or ethnic stereotype.

In an overview of technical papers for the National Academy of Sciences, Hansen (1996) also reports that stereotyping is a significant influence in the pursuit of majors in science and technology. She concludes, “Stereotyping manifests itself in childhood, shaped by the family environment, friends, and community” (p. 79).

A particularly pernicious stereotype has resulted in the so-called gender gap. Hansen enumerates its more serious elements, as culled from her own extensive literature review:

> Choice of [academic] program and career are affected by gender stereotyping. For example, analyses show that there seem to be “male” and “female” specializations in science and technology…Gender stereotyping may also influence scholastic achievement, as well as program choice…There is a perception of hostility of the scientific community to accept women…there are few role models to encourage women

> to pursue studies in science and technology and provide examples of successful careers in the scientific community…The academic and career path is seen as inflexible to women – reentry is difficult and women are led to feel they must choose between a career and a family. (p. 80)

Whether due to a stereotype or outright prejudice, issues of gender bias are a serious international problem that have been and will continue to be studied extensively. In fact, many of the persistence studies that are discussed later in this chapter for other reasons involve programs and initiatives designed to improve the percentage of girls in the science "pipeline" (Didion, 1996; Farenga & Joyce, 1998; Farmer, Wardrop, & Rotella, 1999; Gavin, 1996; Jayaratne, Thomas, & Trautmann, 2003; Jones, Howe, & Rua, 1999; Nauta, Epperson, & Waggoner, 1999; O'Brien, Martinez-Pons, & Kopala, 1999; Smith & Hausafus, 1998; Taylor, Swetnam, & Friot, 1999; Thielen, 2001).

The point, for the purpose of this research, is that many of the special programs and interventions prescribed to overcome these serious gender biases incorporate remedies that encourage boys to pursue a science career as well. Examples of these approaches that will be examined later include role model intervention programs, awareness related to science jobs, participation by mothers, relevance to everyday life, and hands-on experiences. Other studies reference special summer programs and authentic research experiences.

The issue of self-concept, or self-efficacy, has been identified as the strongest predictor of achievement in science (O'Brien, Martinez-Pons, & Kopala, 1999; Simpson & Oliver, 1990; Talton & Simpson, 1986). Certainly this factor cannot be separated from the influences of family and gender as well the influences of ethnicity and SES. Equally certain is the fact that regardless of how excellent and profound the high school science-related influences – the focus of this paper – may be, it is unlikely that they can offset any systemic problems within the family and culture related to gender, ethnicity, and SES.

In 1991 when the prestigious journal *Science* began to evaluate the first serious efforts of the previous two decades to improve representation of minorities in science and engineering, it noted small but significant increases in the numbers of Ph.D.'s awarded to American Indians, African American, and Hispanics (Malcom, 1991). A year later, when the journal wanted to find out why 65% of minorities abandoned their interest in science and engineering early in college, compared to 37% of whites, it talked to dozens of minority science students from high school through college. Though the students reported little overt discrimination, many decried "an insidious set of academic and social obstacles blocking their path: third-rate early educations, low expectations from teachers, anti-intellectual peer pressure, and a cultural gap between the world of research and that of their families" (Culotta, 1992, p. 1209). This brain-drain (to continue the "pipeline" metaphor) which began well before college, persists today and illustrates again how all of the factors and influences both inside and outside the classroom are intertwined.

In addressing these social obstacles, Bonous-Hammarth (2000) examined the factors associated with the persistence in science majors of 330 minority undergraduates. She suggests:

> In relation to the findings of the present study, educators may need to provide African American, American Indian, and Chicano/Latino students, particularly those pursuing SME majors for which attrition is high, with opportunities to help them better understand the climate and culture they will experience in college and in SME-related professions. (p.110)

As was done with the studies relating to gender, many of the studies related to ethnicity and SES will are cited elsewhere in this paper because they also involve special science-related experiences or deal with other significant problems. For example, in the study by O'Brien, et al. (1999), 415 eleventh graders in a parochial school were surveyed to assess their mathematics self-efficacy, ethnic identity, and career interests in mathematics and science: "The major findings of this study were that (a) career interest in science is predicted solely by science-mathematics self-efficacy, (b) self-efficacy is predicted by academic performance and ethnic identity, and (c) academic performance is predicted by income level" (p. 234). Other more recent studies include works by Brazziel & Brazziel, (2001); Cooper, (2003); George, Neal, Van Horne, & Malcom, (2001); Jayaratne, Thomas, & Trautmann, (2003); Quita, (2003); Simpson & Oliver, (1990); Talton & Simpson, (1986).

Family

Numerous studies consistently demonstrate the profound impact that the family has on all aspects of children's lives, including their education and career decision-making process. Most of these studies do not evaluate the impact of the family on science interest per se, but their generalizations would certainly apply. (Conversely, the absence of a supportive family could also impede a child's decision-making process). In addition, many of the non- school-related influences that will be mentioned later in this part of the review relate to the family in some way (e.g., visiting a museum or science center, emphasizing science education and grades, or watching science programs on TV).

Several studies focused particularly on the interplay between the family and science achievement. When 80 mothers of minority students were asked via telephone "to identify those aspects of family support that have the most influence on students' learning in mathematics and science" (Smith & Hausafus, 1998, p. 111), a multivariate analysis yielded three factors: helping students to see the importance of taking advanced science and mathematics courses by emphasizing the importance of mathematics in today's careers, setting limits, and visiting science/mathematics exhibits and fairs with their child. The degree of influence of the family declines as students enter middle school (George, 2000, 2003; Mau, 2003).

The family also plays a significant role in framing a child's attitude towards science, according to a study conducted by Ramey-Gasset (1997). One of the ways in which this might happen is through the careers of the parents, though the literature is somewhat unclear on this point to date. For example, Atwater and Wiggins (1995) found that the science and mathematics educational and career plans of urban children were influenced by their parents' occupations, but Mickelson and Velasco (1998) discovered virtually no relationship between mothers' occupations and their daughters' career plans. In fact, Handel (1991) discovered that even daughters whose mothers were scientists did not plan a career in science.

Another way, according to Byrne (2000), in which the family potentially influences its children is through "parental expectations, aspirations, and internal characteristics" (p. 27). He cited numerous studies supporting this premise that did not specifically refer to science. Of those that did link to science, some were negative. For example, Andre, Whigham, Hendrickson and Chambers (1999) reported misperceptions within families, such as the belief that science is not important until the child is older, that boys are expected to perform better than girls, and that careers in science were more suited for men.

The fact that families' attitudes towards science were often more negative than positive was also reported by Simpson and Oliver (1990). However, this same study implied that, in the words of Byrne (2000),

> Early childhood experiences were perhaps the most important predictors of young people's attitudes toward science. If the child does not receive sufficient support from the

> family, or is exposed to little or no science during middle school, he or she is less likely to elect science classes. (p. 28)

A final way in which families influence children regarding science is through participating in science-related activities. For example, Ramey-Gassert (1997) cited separate research studies, one by Downs (1989) and the other by Seidman (1989), who noted the benefits of an urban after-school science and math resource and activity center and a science/mystery museum program, respectively.

Another example, reported by Chandler and Parsons (1995), describes a mother-daughter club established for the express purpose of preventing the moms' feelings of self-doubt, anxiety, and lack of confidence in science from being passed on to their daughters. The club successfully incorporated role-model intervention and hands-on experiments – two subjects dealt with later in this chapter.

Societal

The three subcomponents of this category, as identified by Byrne (2000), are mass media, role models, and groups. Mass media includes television, computers, and computer applications such as using the Internet. Because most of the research regarding the use of technology as it relates to science is in the context of schools and education, this discussion will be left for later. Only those studies that looked at the influence that TV has had on science and career aspirations outside of the classroom will be immediately cited below.

Byrne cites research by Oremord, Rutherford, and Wood (1989) who reported that their study of twelve to thirteen year-olds indicated that the frequency of watching television and interest in science were related. They concluded that "television should be considered a potentially significant factor in regards to young children's and young adolescents' attitudes towards science" (p. 18). In another study (again cited by Byrne) of the attitudes of 5,432 eleven-to-fifteen-year-old students, Gibson and Francis (1993) corroborate this observation, adding that "young people who preferred watching current awareness programs were more interested in science than students who preferred soap operas" (p. 18).

In another study (cited by Byrne) of six-to-ten-year-olds and their television viewing patterns, Potts and Martinez (1994) drew the following conclusions:

1. In general, scientists are not perceived by children to be villainous or undesirable models but are seen as good characters;
2. Children appear to view scientists as potential role models and positive social characters;
3. Cartoon-viewing shifts the image of scientists in negative directions;
4. There exists a cultivation effect: the common negative presentations of scientists in television programming frequently lead viewers to incorporate those images into their belief systems;
5. Compared with other studies, children appear to have more positive views about science;
6. Boys evaluated scientists more positively than girls;
7. Girls exhibited fewer science interests. (Byrne, 2000, p. 19)

They conclude this "mixed bag" of results by observing that children's poor performance in science and math might be, at least in part, related to the aftereffects of the influence of TV on their behaviors, beliefs, and cognition, with excellent programs like "3-2-1 Contact" notwithstanding.

The next subcomponent in the continued use of Byrne's hierarchy is role models, which his study identifies as females successful in science and technology, family members, peers and playmates, business and industry mentors, teachers, and popular role models. Family members have already been dealt with, and no studies were found concerning peers and playmates that had to do with science. Business and industry mentors interacted with schools; therefore, they will be considered later under the heading of middle and secondary school-related Influences.

All of the studies cited by Byrne reported the significance of role models in improving girls' attitudes towards science and technology careers while a few added that the benefit to boys was also evident but less pronounced (Evans, Whigham, & Wang, 1995; Moffat, 1992). The studies often indicated the negative problems of a dearth of role models (lack or awareness and absence of gender appropriate role models having similar ethnic/social origins) more than the proven benefits of existing programs. The research by Evans, et al. did point out that they targeted ninth-grade students because it was "at this level girls begin to make critical academic choices in terms of their future participation in science courses" (Byrne, 2000, p. 23).

The last subcomponent in this section as identified by Byrne was groups, including parents and families (who have already been discussed), teachers (who will be discussed later in this chapter), peers, and community. The research presented by Byrne had findings ranging from no peer effect (Moffat, 1992) to the significant peer effect that peers "might be a very powerful factor influencing students' attitudes toward science" (p. 30). The vulnerability of girls to peer pressure and the tendency for elementary children to form sex-segregated peer groups was also noted.

Pertinent to attitudes about science was a study by Coddington and Deb (1997), whose work is cited by Byrne as follows: "noted that both girls and boys felt comfortable learning about science and technology in a computer-based, peer-guided environment" (Byrne, 2000, p. 30). Another study by Mayer-Smith, Pedretti, and Woodrow (1999), also cited by Byrne, "indicated that secondary students valued their ability to interact with peers with science instruction" (2000, p. 30). Finally, Fear-Fenn and Kapostasy (1992) were cited for their observation that peer pressure should be used as a positive force to encourage females to participate in math and science.

The community has vested interests in promoting the awareness and pursuit of careers in science and technology, not the least of which is to increase the number of students in the pipeline. It is also a logical hub of coordination between schools, businesses, and industries through all kinds of partnerships that facilitate everything from information exchange, job awareness, job training, and community enrichment.

Of special significance is the community's role in helping to establish tutoring partnerships, mentoring opportunities, teacher development and training programs, corporate sponsorships, and cultural enrichments like museums and science centers. Because almost all of these endeavors involve networking with schools, further discussion of their effects will be investigated later.

Elementary School-related Influences

The importance of elementary school as a harbinger of a future career in science is not farfetched and was one of the conclusions of Simpson and Oliver (1990) in their *Summary of the Major Influences on Attitude Toward and Achievement in Science Among Adolescent Students*:

> If adolescents enter middle or junior high school with positive feeling toward science, and experience success during their initial courses in science, it is likely that they will elect to take and will be successful in additional science courses. This, in turn, leads to a

> positive commitment to science that influences lifelong interest and learning in science. (p. 14)

The research investigating the relationship between a student's elementary school experience and future aspirations in science reveals several commonalities. First, of the limited number of studies that could possibly be construed to relate to science and technology, most of them dealt with mathematics, which along with reading appear to receive the most attention of all the subjects. (The importance of success in mathematics will be revisited later in the review.)

Second, most of the relevant studies overlap issues of family or stereotypes of gender and ethnicity, which have been discussed earlier in this chapter. For example, a study of K-6 Iowan students by Andre, Whigham, Hendrickson, and Chambers (1999) reports that:

> Boys perceived higher competence in physical science. All children perceived physical science competence lower than reading or math competence. Parents perceived boys as more competent in science… Grade 4-6 children also expected lower grades in and attached lower importance to physical science than to reading. Parents perceived science as more important for boys and expected higher performance of boys. Jobs related to math or science were seen as more male dominated. (p. 719)

Third, almost all of the references to this topic are from the 1960's through the mid-1980's. If there are any more recent follow-up studies to the findings of several decades ago, they must not yet have made it into the literature. A more general study entitled *Lasting Effects of Elementary School,* by Entwisle and Hayduk (1988), confirms the contentions about mathematics and stereotyping.

Middle and Secondary School-related Influences

The next phase of this literature review will move beyond the science-related influences of the elementary school-aged child to those of the middle school-aged and high school-aged student. These factors can be divided into those experiences that occur inside or outside of the classroom (issues of place, i.e., where?) and those experiences that occur inside or outside the typical school day/year (issues of time, i.e., when?). Ramey-Gassert (1997) calls the science-related influences that occur outside both the conventional walls and time of the school *informal science* learning environments, in contrast to the more formal ones that take place within the traditional confines of the classroom (p. 433). An extensive list of over 30 informal science learning environments and experiences is itemized by Phillips, et al. (2000) but is by no means complete. It encompasses readings, movies, visitations and tours, discussions, repairs, and hobbies.

In this section, after an introduction to the importance of informal learning-places, research describing informal "place/time" programs for middle school-aged students will be reviewed, followed by research describing informal "place/time" programs for high school-aged students. Research enumerating and discussing the *formal* "place/time" influences will be in the next section. This lengthy introduction with numerous quotes serves the purpose of providing a backdrop for what ideally should be a description of the more formal - in terms of "place/time" - learning environment of the classroom.

In a way, most informal learning environments are a kind of museum, whether they are a museum in the traditional sense or a zoo, aquarium, science center, science club, national park, summer camp, or some other learning center. In every case, (though to varying degrees) as described by Griffin (1991), they offer the following advantages:

> 1. Provide experiences which deepen understanding of scientific ideas (learning science);
> 2. Provide opportunities for carrying out investigations using scientific processes (learning about science);
> 3. Provide opportunities for conducting exercises which lead to acquisition of scientific research skills (doing science). (Byrne, 2000, p. 39-40)

In her own review of the literature of science learning beyond the classroom, Ramey-Gassert (1997) cites 30 articles that discuss museums and an additional 16 that deal with related science centers, field trips, and the like. For example, she mentions Wellington (1990), who "pointed out that students in science centers display interest, enthusiasm, motivation, alertness, awareness, and a general openness and eagerness to learn, characteristics that tend to be neglected in school science" (p. 435), and Semper (1990), who observes that

> Science centers provide a rich learning environment for students with a variety of learning styles while implementing four themes in educational theory: curiosity or intrinsically motivated learning, multiple modes of learning, play and exploration during the learning process, and the existence of self-developed world views and models among people who learn science. (p. 435)

Another researcher cited by Ramey-Gassert was Csikszentmihalyi (1987), who derived an entire psychological underpinning for informal science learning environments through a study of museums:

> But learning involves the whole person, not just the rational mind. It involves the senses, the desires, the longings, the feelings, and the motivations as well. The difficult thing with people is to turn them on to learning. Once they are motivated, once they are ready to start, the major obstacle is over. How to present information is secondary because the

> learner will go out and find the information no matter how difficult it is to get it. The question is how to get them to want to learn in the first place. (p. 435)

Byrne's evaluation is that they are successful because:

> Product is not emphasized, inquiry is sparked, open-ended questions are generated, and students actively participate and appear involved. Students in these programs looked forward to attending, told their parents what they were doing, recommended the program to their friends, thought the program to be fun, and returned to the museum on their own after program completion. (p. 42)

Finally, in a series of studies, Farenga and Joyce show the importance of informal science experiences in conjunction with the classroom. In 1997, they completed a study of 539 elementary school students between the ages of 9 and 13. They followed this in 1998 with a similar study of 349 elementary students in grades three to six. These studies categorized informal science-related experiences in those related to life science (e.g., caring for plants or animals), physical science (e.g., fixing something, model rocketry) and general learning attributes which develop basic research and data collection skills (e.g., read science articles, listened to science news). They concluded that teachers need to "be aware of students' prior experiences and allow them to adapt curriculum to maximize students' prior knowledge and increase learning" (1998, p. 283).

A third study (Joyce & Farenga, 1999) sampled 111 high-ability elementary students also between the ages of 9 and 13 and indicated that the aforementioned categories of informal science-related experiences were important predictors of future course-taking in science. All of these studies are contextualized in the following quote:

> When viewed as a two-pronged approach to learning, informal science experiences and classroom science lessons can effectively form a synergistic relationship that may enhance students' future interest and participation in the field of science. Parents can provide exposure to many informal science-related experiences through books, television programs, zoos, museums, hobbies, clubs, web sites, and family vacations. (Farenga & Joyce, 1998, p. 69)

Influence of "Place/time" (Formal) Programs for Middle School

Rohrer and Welsch (1998) evaluated a summer program that "was designed to provide a non-threatening, all-female environment in which the participants could see and learn from female scientists and science teachers who were models of women successful in a math or science career" (p. 289). This was in response to a U.S. Department of Education's National Center for Education Statistics report (1996) which stated that despite the fact that there were about as many women as men in the labor force, only 8% of engineers, 27% of natural scientists, 32% of the mathematical and computer scientists, and 9% of physicists were women.

Their (Rohrer and Welsch) literature review indicated that two primary factors of this under-representation were weak math confidence and poor self-image. In fact, math confidence had the greatest correlation with math performance than any other variable. The problem of self-image, according to their study, was because girls had "fewer experiences actually doing science, and less exposure to a variety of scientific equipment" (p. 288). The evaluations by the students at the end of the summer indicated that the program was a success. Reasons given were that the program was authentic, was relevant, was diverse in content and process, provided experience in doing math and science, and had a positive and cooperative environment. Consequently, Rohrer and Welsch concluded that schools should:

> Allow bright female students to work together on science projects (and) identify female mentors and role models. Schools could help this group of young women gain confidence by providing guided practice with equipment prior to using it in class; by maintaining a psychologically safe environment in which to reflect upon, discuss and explore questions and solve problems; and by allowing young women more preparation time before making presentations or responding to questions. (p. 291)

Another science summer camp was evaluated by Gibson and Chase (2002) and employed a rigorous mixed-method approach. The goal "was to stimulate greater interest in science and scientific careers among middle-school students" (p. 693). The means to this end was two intense weeks of engaging in inquiry-based science activities. Their literature review indicated that such an approach should have "positive effects on students' science achievement, cognitive development, laboratory skills, science process skills, and understanding of science knowledge as a whole when compared to students taught using a traditional approach" (p. 694).

The quantitative results showed that students who did not participate in the study later showed a more marked decline in science interest than those who had. The qualitative results indicated that over two thirds of the students enjoyed the experience and that the program increased their interest in science. The authors concluded that inquiry-based science activities, if incorporated into the regular school science experience, would have similarly positive effects.

Finally, Barab and Hay (2001), studied a middle-school summer science program (called an "apprenticeship camp") that involved 24 students in a "2-week long camp with 'real' scientists engaged in 'real' research" and was strictly qualitative" (p. 70). Through field notes, videotapes, and interviews, the students were evaluated as they engaged in "six different participatory science contexts organized around particular investigations" (p. 80). These investigations centered on themes of drug exposure during development, hormone agents, bats' sonar, and ultra-high speed communications and computing. Included in this report was an exhaustive literature review of apprenticeship learning, "the practices of scientists and how scientists come to know them" (p. 73), and "engaging K-12 students in doing science" (p. 74). The difference between an investigation and apprenticeship is that:

> While an investigation is a comprehensive perspective focused on actively engaging learners in authentic, scientific inquiry, apprenticeship goes one step further and situates this investigation in the context of the well-worn path of a particular scientist's research agenda…Rather than "telling" learners about a discipline, apprentices are immersed within a community in which the engage in practices "at the elbows" of more competent peers, experts, or "old-timers." (p. 71)

The authors' (Barab and Hay) conclusions conveyed somewhat mixed results. On the positive side, most students "viewed their work as legitimate" (p. 96) and "were able to gain an appreciation of the situated nature of science" (p. 96). The main detractor was the "limited opportunity to develop a rich and grounded appreciation of the domain in which they were working" (p. 96).

Influence of "Place/time" Programs for High School

Seven summer science programs for high school students will be reviewed in chronological order. The first of these, as reported by Cavallo, Sullivan, and Bennett (1999) was a six-week program involving 75 students each summer that exposed them to the:

> Rigors of academic preparation required for careers in the various health sciences professions, to the rewards of applying such knowledge to direct patient care and

> laboratory research experience, and to the responsibilities associated with health care delivery and research. (p. 294)

The reason such an approach was deemed necessary was because of the critical shortage of workers in the health care field compounded by:

1. Increasing pressure from the public and private sectors to curtail cost.
2. Introduction of new, sophisticated health technologies.
3. Growing numbers in the aged population.
4. Increasing attention to individuals with chronic disabilities.
5. Drastic developments in diseases such as HIV. (p. 294)

The program consisted of a core curriculum of five courses, a clinical practicum involving side-by-side patient care with a professional and the writing of a scientific paper, and a research practicum that included mentoring and a project. The methodology, which incorporated a longitudinal survey and anecdotal data, revealed that “the program has effectively involved talented high school students from underrepresented groups in the intensive and enriching experiences of the health sciences summer academies” (p. 298). The fact that 81% of former participants chose a major in science (almost half of which were in a health-related field) supported this claim. In addition, participants who formed lasting friendships enjoyed a “forum to comfortably display their academic talents, which may be subject to peer pressure in regular school settings” (p. 299).

The purpose of the second summer science program, as reported by Phillips, Chandreasekhar, and Barrow (2000), was:

> To determine the interest in physical science careers and activities of a group of females who voluntarily enrolled in a summer, hands-on, residential, physical

> science program, with the long-term goal of determining methods to affect that interest level. (p. 2)

Thirty-two young women entering tenth through twelfth grade participated in the study following their ten-day participation in the residential camp. Four separate instruments were used to assess attitudes toward school science, science-related experiences, science course selection, and general occupational themes. The results were mixed, showing a "fairly strong interest in taking further physical science courses in high school" (p. 7) but little significant increase in interest in building and repairing objects or researching, analyzing, or inquiring.

Stake and Mares (2001) describe two science enrichment programs and their impact on 330 gifted high school students. After a lengthy literature review resulting in a belief that "the traditional pre-post test design used in most studies may be insufficient for measuring the impact of intervention programs" (p. 1067), they employed an expanded methodology that included,

> (a) student subjective ratings of program-related change, (b) student written descriptions of change, (c) parent ratings of student change, (d) parent written descriptions of change, and (e) a third administration of the repeated measures at a 6-month follow-up. (p. 1,067)

Their findings, supported by other studies, showed that family encouragement, influence of science teachers, and performance self-esteem were all positively associated with program benefits and impact. In their words, "Our results provide evidence of the value of a history of positive science-related experiences for continued growth in commitment and confidence to achieve in the challenging world of science" (p. 1082).

Abraham (2002), in her study of the Earthwatch Institute's Students Challenge Awards Program (SCAP), reviewed pre- and post-experience questionnaires from 75 high school participants in this two-to-three week apprenticeship program. Her goal was to answer the question, “How do we encourage and sustain high school students’ interest in science?” (p. 229).

The students’ open-ended responses yielded the following themes:

1. Students reported an increased interest in pursuing a science-related major in college or a career in science.
2. Students reported a positive change in their views of scientists and members of the scientific community.
3. Students reported a positive attitude shift in their perception of science.
4. The social aspect of the expedition had an effect on students that was as profound as the academic experience.
5. Students reported increased knowledge of science content, the scientific process, and the nature of science. (p. 230-232)

These findings confirm her initial model that suggests that “involving students in authentic research projects and allowing them the opportunity to engage in scientific work alongside practicing scientists lead to increased excitement about science as well as increased retention of students in science courses” (p. 229).

The Rutgers Astrophysics Institute (RAI), according to Etkina, Matilsky, and Lawrence (2003), is a month-long science program for gifted high school students that has an “emphasis on inquiry processes, real laboratory work, challenging content, interactions with practicing scientists, and use of technology” (p. 962). Its design follows the four stages (or characteristics) of cognitive apprenticeship, citing Barab and Hay (2001), which are:

1. The development of learning contexts that model proficiency.

2. Providing coaching and scaffolding as students become immersed in authentic activities.
3. Slowly removing scaffolding as students develop competence.
4. Providing opportunities for independent practice so that students gain an appreciation of the use of domain-related principles across multiple contexts. (p. 962)

Etkina, et al. (2003) evaluated 86 New Jersey high school students who participated in the program over several years using a battery of assessments including observations of student discussions; student journals; a "nature of science" survey; a "use of models in science" questionnaire; a response taxonomy to classify the responses of the previous two assessments; and a free response problem from an AP (Advanced Placement) Physics Exam. Their results were:

1. Observations of student discussions, an analysis of students' journals, and student presentations showed that students can engage in discussions and write narratives about complex science content, distinguish between observational data and models, devise testing experiments, and reflect on the analysis and interpretation of X-ray data encountered in class.
2. A statistical analysis of student performance showed that students' performance on a selected AP problem improved significantly as the result of the ASI.
3. An analysis of student presentations showed that students were able to initiate an independent research project and collect data, and some were capable of sophisticated analysis and interpretation of data.

4. An analysis of student journals' narratives, their questions, questionnaire responses, and presentations showed that their perceptions about science processes and learning approaches changed owing to their experiences, and that these changes persisted after instructional part of the program was over. (p. 980-981)

Knox, Moynihan, and Markowitz (2003) evaluated SSA – the Summer Science Academy at the University of Rochester. The program focuses on hands-on laboratory investigations and independent experiments in biotechnology because, according to the National Center for Educational Statistics (2000), "educational research data indicates that there is a positive relationship between the use of science equipment and student performance" (p. 471).

Knox, et al. (2003) used several evaluation methodologies, including a pre/post survey which indicated that the program had a "significant *immediate* impact" (p. 474), and qualitative interviews which demonstrated student enthusiasm, "access to high-tech equipment, and exposure to research scientists and their work" (p. 476). Students also confirmed SSA "as being a positive influence on their performance in advanced science courses as well as their desire to pursue a career in science" (p. 476). Finally, of the students who responded to a follow-up survey, 75% indicated that the program contributed greatly to their interest in a science career.

Bell (2003) reviews another apprenticeship program that lasted eight weeks and was strictly qualitative. Ten volunteers and the scientists with whom they worked were interviewed. Except for the inherent limitations of any program that lasts for such a short time, the scientists' assessments were generally positive, and described "their students as engaged in the development of research methods, data collection and data interpretation" (p. 502). However, the interviews with the students were less encouraging:

> Unfortunately, most students exhibited little change in their understanding of the nature of science and their understanding about scientific inquiry… the results of this investigation do not support the intuitive assumption that students will learn about science simply by doing science. (p. 503)

The additional components that are necessary to elicit more constructive results will be forthcoming in a later section of this review about pedagogical practices.

Influence of In-school Science-related Factors

At this point in the review of the literature, it is wise to reiterate the purpose of this research – to investigate what high school science-related factors influenced practicing scientists. As was stated under the limitations section of chapter one, the goal is neither to orient high school science-related experiences towards the sole purpose of creating scientists (Hurd, 1998) nor to identify some single factor that will be the turning point for potential scientists who are on the brink of choosing a career (Woolnough & Guo, 1997).

Instead, the focus of this review has been to identify all possible common factors that *might* be significant in propelling a student towards a career as a scientist. Thus far all the studies have relied primarily upon responses from students – *not scientists* – to reach their respective conclusions. Once these factors have been identified as being significant, at least insofar as "potential future scientists" are concerned, then actual scientists can be queried as to the personal extent of their impact, if any, in their lives.

This literature review now moves from the non-school “place/time” science-related factors into the phase that deals with in-school science-related factors. In an international study, Woolnough and Young (1997) set out to determine:

> Whether a student would, or would not, continue with their [sic] school science into courses in higher education and thence to scientific careers. A secondary aim was to see why some students who were good at the physical sciences chose pure sciences and others went into engineering. (pp.105-106)

The methodology included questionnaires completed by science department heads, school visitations, student and staff interviews, and student questionnaires which were divided into “potential scientists” and non-scientists for the sake of comparison. The similarities in responses between the countries was striking:

> Potential scientists prefer planning their own experiments…gained more from extended practical projects…found involvement in science and technology competitions to be great fun and useful…wanted their science to be both well structured by the teacher and provide opportunity for student planning. (p. 109)

Note the interesting paradox in the last phrase – preferred courses were *both* teacher-centered and student-centered. The most influential factors for potential scientists, according to the student questionnaires, were:

> The quality of science teaching, supportive mathematics teaching, the intellectual satisfaction and level of difficulty in school science, involvement in science competitions, likely-job satisfaction, status and salary in science, and…the influence of scientific hobbies at home. (p. 111)

Woolnough and Guo (1997) conclude by making several recommendations that, in their opinion, would encourage students to persist in a science-oriented career path. The first is to improve the quality of science teachers and their teaching, especially through forging genuine partnerships between teachers in high school and teachers in college. The second is to improve the quality of the science curriculum in order to “ensure that it is stimulating, challenging, accessible and relevant” (p. 114).

The third recommendation is to promote the challenge and stimulation of extracurricular activities in science, such as science clubs, competitions, school-industry links, and especially the engagement of students in their own research projects. The next two suggestions are to increase the attractiveness of the courses in higher education and the careers in science. They perceive private and government roles in making this happen.

The last proposal is to encourage the influence of the home via scientific, crafts, and technical hobbies, especially during a child’s formative years. They perceived the media as having a supportive role in this. The rest of this section of the literature review will expand upon and substantiate the first three recommendations.

Influence of Previous Courses and Success

In Woolnough and Guo’s second recommendation, we should ask the question what does “stimulating, challenging, accessible, and relevant” mean? Certainly a significant part of the answer depends upon the quality of instruction – a multifaceted component that will be addressed later in this review. The literature does indicate that math and physics, in particular, are essential elements of a challenging science curriculum, and hence preparatory for pursuing a career in science. Reynolds (1991) found this to be true in his longitudinal study of over 3000 7th grade public school students. He concludes:

> Prior grades and grade 7 science and math achievement all had pervasive influences on the process of schooling… The magnitude of the indirect effects of prior grades and the direct effects of prior achievement suggests that the time before adolescence, possible early schooling, is of critical importance for middle school success. (p. 9).

Moving to the next grade, Trusty (2002) uses a nationally representative sample to discover that:

> For women, 8th grade math tests scores positively influenced math course-taking in high school, which in turn positively influenced later choice of science and math majors. For men, completing high school physics had a significant positive effect on choice of science and math majors. (p. 1)

Once a student enters high school, the AP (Advanced Placement) courses are often the benchmarks of challenge and rigor. In their review of previous studies and the conducting of their own, Morgan and Maneckshana (2000) found that "Participation in AP may result in a greater propensity to continue in the area of study related to the AP courses taken in secondary school" (p. 3). In particular, they claim:

> After taking an AP Exam, many students complete their college degree in the subject area of their AP Exam. Those taking AP Biology, Physics, Calculus, …were most likely to major or minor in those disciplines or a closely related discipline. (p. 6)

Finally, completing the ascent through the scholastic ranks, a study of almost 2000 introductory college physics students reveals that "Higher college grades appear to be associated with high school courses that hold to rigorous standards, but take their time" (Sadler & Tai, 2000, p. 126). This is important because physics is often the "gatekeeper" for further courses in science.

Most of the studies that investigated the influence of previous courses and success/grades were in the interest of improving diversity in the scientific community. They are presented here both to support the conclusions of the several studies already referenced as well as to illustrate the challenge in attracting and keeping underrepresented minorities (URM). It is assumed that those factors that encourage minority students to take and persist in science, technology, engineering, and mathematics (STEM) courses are probably true of all students.

That there is a problem there can be no question. In a sweeping review of over 300 quantitative and qualitative studies of URM conducted on behalf of The American Association for the Advancement of Science and the National Science Foundation, George, et al., (2001) presented the following findings:

1. The three most important variables that contribute to bachelor's degree completion are intensity and quality of the secondary school curriculum, tests scores, and class rank/grade point average.
2. National and state school educational policies may limit resources for K-12 schools, particularly in science.
3. Taking mathematics courses beyond Algebra II, such a trigonometry or pre-calculus, is particularly key for African American and Hispanic American students.
4. Factors that are associated with racial/ethnic differences on standardized and college admissions tests as well as entry into STEM majors include: a) the number of advanced mathematics and science courses taken by students and offered by high schools; b) teacher effectiveness; c) school resources. (p. 7)

Unfortunately, numerous obstacles stand in the way of taking advantage of the insights expressed above. Citing a 1994 National Action Council for Minorities in Engineering, Inc. (NACME) report, Gilroy points out that:

1. Minority students tend to attend schools that are less likely to offer advanced placement and college-level courses. Most distressing is the finding that the 74% of minority girls who wanted to take advanced or AP math were the most likely to say they had no access to the courses.
2. Minority students report greater negative peer pressure in the decision to enroll in math and science courses: their friends tell them not to take certain courses because the courses are too hard or are for “geeks,” a popular stereotype.
3. 63% of minority students feel that they will have to work harder to succeed in math and science, and 67% say that they have not done well in other math and science classes. (p. 39)

Lastly, even though 86% of the students and 90% of the parents expect their children to go to college, neither group seemed to understand the consequences of not taking advanced classes (p. 40).

A few other studies deserve to be mentioned because they express their findings in terms of attitudes such as self-efficacy and enjoyment, providing a different slant on the same problem. When Farenga and Joyce (1998) studied science-related attitudes and science course selection, they discovered significant correlations between the total number of science courses taken and interest in a career in science, and one between the number of physical science courses with enjoyment of science and interest in a career in science (p. 249).

Shernoff and Hoogstra (2001) also showed in a national study of 184 high school students that “Interest and enjoyment in high school math and science classes are significant predictors of academic performance in college, whereas high school grades are not” (p. 81). These two studies, though not specifically about minorities, show that the following four that are about minorities yield the same results.

Both O’Brien, et al., (1999) and Mau (2003) looked at self-efficacy as a predictor of persistence in a career in science. Self-efficacy affects motivation, and motivation is enhanced by interest and enjoyment. In his study of 415 11th grade parochial students, O’Brien found that “skills in mathematics are a key requirement for success” in science and engineering (p. 231). Likewise, in a nationally representative sample of almost 25,000 students in over 1000 schools, Mau concluded that “Academic proficiency and math self-efficacy were two of the strongest predictors of persistence in [science and engineering] careers” (p. 234).

A study of three African-American students who began college considering a career in SE was conducted by Lewis and Collins (2001), and corroborated what they discovered in their literature review that “the only significant predictor of interest in math/science careers was math/science confidence regarding educational requirements” (p. 600). In the last study for this section of the literature review, Joyce and Farenga (1999), building upon their own earlier studies, found that “interest in science and informal physical science related experience predicted 42% of the variance related to the number of physical science courses selected” (p. 431).

Influence of Textbooks, Other Literature

Very little research has been conducted about the relationship between textbooks and the pursuit of science as a career. Sadler and Tai (2000) reported “no significant difference in college physics grades among any or the major texts used in high school physics. While there may be a difference between alternative treatments or topics covered, this study failed to reveal it" (pp. 126-127). They go on to comment that:

> A considerable portion of the text can be consulted over the course of the year, but there appears to be little advantage to covering it all, spending large amounts of time reading it… Covering a limited set of topics, dealing primarily with issues in mechanics, appears to be beneficial. (p. 126)

This idea of 'deep, not wide" coverage is a factor related to inquiry based learning – a topic addressed later in the discussion of pedagogical approaches.

Influence of Extracurricular and Co-curricular Experiences

Informal ("place/time") science-related experiences were discussed earlier and defined as events and activities that took place outside immediate school purview. However, several events and activities frequently take place within the curricular confines that for all intents and purposes can be considered "informal" as well. In other words, they too are "motivational, engaging, enjoyable, and non-threatening" (Ramey-Gassert, 1997, p. 435). These activities, found in some schools, include science competitions and fairs, science clubs, and field trips.

Though much has been written about these activities, very little of it focuses on their impact on persistence towards a science career. One study which did was conducted by George (2003) and investigated "predictors of attitudes about the utility of science" (p. 439). It found that "participation in science activities such as science fairs and science clubs are associated with higher attitudes about the utility of science" (p. 446), but to a lesser extent than other factors such as science self-concept and teacher encouragement of science.

Taylor, et al., (1999) surveyed women science educators and discovered that "Women remembered classes in which the teaching/learning methods included field trips, labs, experiments, and science fairs" (p. 34). The reason for this response was because these activities involved hands-on instructional techniques, a subject that will be the focus of a later section. The point is that, like in the previous study, the real impact of these activities has been weakened.

In a similar vein, a study of science competitions – in particular the prestigious Westinghouse Science Talent Search (now administered by Siemens) – indicated that the predictive value of such competitions was because participation was an indicator "of characteristics like originality, persistence, and dedication, which are important for success in a scientific career" (Marsa, 1993, p. 21). Another factor contributing to the predictive value of science competitions is "the mentoring relationship that evolves of necessity through the process of entering a competition" (p. 22). Mentoring, which involves encouragement, nurturing, and teaching, is also considered later in this chapter.

Science clubs may or may not be associated with the school, but in either case the value of the club, like the value of a science competition, has more to do with what it engenders than the club itself as the following analysis by Byrne (2000) demonstrates:

> Such informal organizations provide stimulating, individualized learning environments, encourage extra-curricular science experience, reinforce positive attitudes toward science, and acknowledge the value of scientific research for the community. They also provide a meeting place for people with similar interest. Science clubs are also about having fun. (p. 44)

One example of a science club is JETS – Junior Engineering Technical Society. Established over half a century ago, JETS is actually an integrated set of programs that serves 25,000 students in 2,500 high schools and is "dedicated to informing students about the role of engineers and engineering in their lives and to encourage those students with the ability, interest, and dedication to consider engineering as a career" (Peralta, 1998, p. 3). The success of the JETS programs comes from addressing some of the common shortcomings in American education:

> A focus on breadth of knowledge rather than depth of knowledge, a focus on the method of learning whereby the teacher tells students what to remember rather than the teacher leading the students to understand concepts and their relationships to real problems. (p. 2)

Consequently, JETS training programs for teachers and students emphasize multidisciplinary teamwork, higher-order thinking skills, and real-world problems. These important strategies will be examined in greater detail in the last section of this review.

The final informal science activity usually associated with schools is the field trip. The research cited by Ramey-Gassert (1997) showed that "Productive field trips where students focus on learning objectives enable students to connect more abstract classroom learning with real-world science" (p.438). Often they are also "hands on" and have a substantial "novelty" effect. As before, the value of "real-world" (authentic) and "hands-on" will be addressed later. Suffice it to say that:

> The type of science that appears to be most effective in encouraging future scientists and engineers, a stimulating, relevant, challenging and accessible curriculum, well taught and supplement by opportunities for extra-curricular projects in science, seems to be equally appropriate for all. (Woolnough & Guo, 1997, p. 113)

Influence of Technology

Educational technology comes in many different guises, and its prevalence and influence is only going to increase. This is true not only because new technologies are continually being added to the mix, but their declining prices mean greater affordability for a greater number of classrooms. A tangential factor concerning the role of technology in the educational process is the tacit assumption on the part of students that the technologies that they have grown up with will be a natural part of the learning process, just as they have been in other aspects of their lives.

Any list of educational technologies will include the computer and internet resources but will also quickly be incomplete as new technologies and their applications filter into the classroom. However, because of their relative novelty, the study of the influence of these technologies is only presently emerging and is not yet definitive. For example, in her study of 600 middle school students from middle class rural and suburban communities across the country, Koszalka (2002) examined the “strengths of the relationships between predisposition characteristics of students and interests in pursuing science careers under different classroom environments, namely those that regularly integrated web resources into science teaching and those that did not” (p. 30). She discovered that even though the use of technology resources at home did not predict student science career interest (contrary to what her literature review had said), the regular use of web resources in the classroom was a positive factor but with different effects on boys than on girls (p. 35).

Certainly as more studies are conducted and their results are reviewed, a consensus as to the precise import educational technologies have on students and their career paths will evolve. It is likely that “the use of advanced technologies seems to aid people’s studying the world as a member of that world” (Goldman-Segall, 1998, p. 9) will be a common theme. As this ethnographic study of the influence of networked digital media on middle school students goes on to relate:

> When a topic is relevant to the lives of young people, then it stands to reason that they will be more willing to engage in the investigation. What makes the study of science

> meaningful and interesting is when scientific problems are embedded in a relevant topic that they can examine as a web of complex ideas. In short, they see the topic as being integrally tied in with their own understanding of the world and its complexity. (p. 9)

Knox, et al., (2003) extend this connection between technology and interest to science persistence:

> Teacher and student access to modern scientific equipment and their increased proficiency in the use of computers, the Internet, and other tools to aid in science education promotes data collection and analysis, and will renew interest and enthusiasm in the sciences by opening up new and interesting scientific avenues to explore. An increase in enthusiasm toward learning science by high school and middle school students will almost certainly have positive effects on their pursuit of scientific careers. (p. 472)

As these quotes suggest (and as will be considered in a later section of this review), technology can play an integral part in making any investigation relevant, meaningful, and interesting.

An increasingly popular and powerful technology is the microcomputer-based laboratory (MBL) with its attendant probe-ware (devices for measuring temperature, pressure, motion, acceleration, forces, voltage, current, light, sound, magnetic fields, pH, dissolved gases, conductivity, etc.). Krajcik (accessed online July, 2004) reports that:

> Microcomputers used as laboratory tools may offer a fundamentally new way of aiding students' construction of science concepts… They also allow students to experience what it is like to do science… MBL provides opportunities for asking and refining questions, making predictions, designing plans and/or experiments, collecting and analyzing data,

> debating ideas, communicating ideas and findings with others, drawing conclusions, and asking questions. In addition, the use of the microcomputer may strengthen students' graphing and problem solving skill. (p. 1)

Hofstein and Lunetta (2003), revisiting a subject they first reported on 20 years earlier ("The Role of the Laboratory in Science Teaching: Neglected Aspects of Research," in the *Review of Educational Research*, 1982), concur:

> When inquiry empowering technologies are properly used by teachers and students to gather and analyze data, students have more time to observe, to reflect, and to construct conceptual knowledge that underlies the laboratory experiences… Furthermore, incorporating appropriate high technology tools can enable students to conduct, interpret, and report more complete, accurate, and interesting investigations. Such tools can provide a medium for communication, for student-student collaboration, and for the development of a community of learners in the laboratory-classroom and beyond. (p. 41)

The role of inquiry in science education pedagogy will be examined later in this chapter.

This incredible litany of potential benefits does not come without certain caveats. First, whether or not MBL or any other technologies will positively influence potential scientists to persist remains to be seen. This is because the widespread and effective use of educational technologies is relatively recent (assuming that they *are* widespread and effectively used), and it takes almost a decade to complete a college degree, finish graduate school, and begin a career in research.

The second caveat is an extremely important reminder and can serve as the introduction to the next section. It is contained in the conclusion of Krajcik's report:

> However, the research indicates that MBL tools by themselves will not develop an environment that will allow students to explore concepts. The teacher and the instructional setting play a critical role in shaping an environment that will allow for an active, constructivist microcomputer-based laboratory setting. Microcomputer-based laboratories are only tools that must be incorporated into science teaching by a skillful and knowledgeable teacher. (p. 4)

Influence of Teachers

There are many ways in which science teachers can positively influence students, encouraging and enabling some to persist towards a career in science. For example, they can provide counsel about science careers, be liaisons to science professionals, and make recommendations about science internships or informal science opportunities. Science teachers can also order their curriculum, employ an effective pedagogical style, and create a classroom environment that promotes doing and discovering science as well as learning science content. (This will be fleshed out in the last section of this review). How science teachers can be role models and turn students on to science with their enthusiasm and knowledge is the focus of the following dozen articles. As Byrne (2000) astutely observes, “Teachers who do not like science will generate students who do not like science” (p. 26).

The literature is replete with studies showing both the positive effects of excellent teachers and the negative repercussions of poor teachers. Several studies contained their own literature summaries on this very topic. For example, George (2003), referring to attitudes towards science, cited researchers that “found that teachers have the greatest influence on attitudes and that teachers could easily bring about changes in attitudes” (p. 441). Academic preparation and the ability to facilitate the pedagogical approaches that are discussed later were instrumental. These results reinforced George's earlier study in 2000 of 444 7th and 10th graders.

Hansen's (1996) overview of the international literature also indicated that "The quality of teaching directly influences a student's scholastic achievements, limiting or enhancing program prospects" (p. 79). On the up side, Hansen notes the significance of the teacher as a role model and value of the student-teacher relationship (p. 80). On the down side, "Poor teaching is a factor that not only can influence the individual's scholastic achievement, but also may inhibit the student's interest in science and his or her attitude toward science" (p. 79-80).

Other inadequate traits were noted in the literature review of teacher expectations and behavior by Hofstein and Lunetta (2003). These included not "practicing what they preach" (promoting certain teaching strategies but not actually using them in the classroom), providing only low-level labs and interactions, and not "encouraging students to think about the nature of scientific inquiry and the meaning and purposes for their particular investigation during laboratory activities" (p. 39).

Perhaps the most egregious consequences of poor teaching were enumerated by Culotta (1992) in her analysis of why so few minorities participate in the scientific enterprise:

> Unlike their parents' generation, today's students report relatively little overt discrimination. But many see an insidious set of academic and social obstacles blocking their path: third-rate early educations, low expectations from teachers, anti-intellectual peer pressure, and a cultural gap between the world of research and that of their families. (p. 1209)

Anecdotal evidence from students in predominantly minority schools told tales of poor discipline, teachers who did not know their subjects, few challenging courses in math and science, and homework that was too easy and only took a few minutes to complete (p. 1210).

Fortunately, there are also studies validating excellent teaching, as the next three reports of high school students show. For example, Stake and Mares (2001), in their evaluation the impact of a summer research program on science confidence and motivation, report that such programs strongly influence science involvement and science confidence.

> In addition, students who had a science teacher model whom they wanted to emulate had greater pre-post gains in science career motivation and reported greater gains in motivation, confidence and knowledge. Having had the opportunity to work with a teacher who presented a positive image of a science professional appears to have prepared students to be more open to enrichment experiences designed to guide them toward involvement in science. (p. 1081)

Another study, ethnographic and interpretive, elicited from college-bound chemistry students their perspectives on learning in the context of their chemistry course. The author (Rop, 1999) summarized the insights in an extremely informative way:

> Teachers need to own real chemistry themselves, to practice it with passion and wonder, and to appreciate continual inquiry, discovery and learning. Teachers need an epistemology which serves as an underpinning framework which flavors and feeds every aspect of their teaching. Only then will they, with their students, be challenged and able to lift their eyes off paper and focus on real, inspired scientific understandings. (p. 234)

Other essential teacher attributes included respecting students, welcoming diversity of opinions, challenging students, arranging formal and informal science experiences (field trips, collaborations, labs, experiments, science fairs, and “hands-on” activities), knowledge, and science appreciation (Taylor, et al., 1999, p. 34).

Two studies from the college ranks confirm these insights. When Gavin (1996) interviewed 16 math majors attending a highly selective women’s college, they described their “best” math teachers as encouraging, enthusiastic, approachable, and generous with their time and help. Some even attributed their pursuit of a math or math education major to their teacher and have even maintained a personal relationship with them after graduation.

When Bauer (2002) used several different assessments to query his college chemistry students about their high school chemistry teachers, he identified six characteristics nearly identical to those already mentioned:

> (a) Teacher enthusiasm, (b) ability to explain and to motivate, (c) knowledge of chemistry, (d) caring attitude, (e) student enjoyment and interest, (f) challenging and rich instruction with experiments and demonstrations. (p. 53)

A fitting conclusion to this section that directly addresses the research question and also puts all the other factors influencing science persistence into perspective was given by Woolnough and Guo (1997):

> Rearranging the science curriculum is not, in itself… a satisfactory solution to improving science education. Teachers are more important than the curriculum they teach. Students need to be inspired by their teachers and challenged and stimulated by the science they do if any of them are going to want to continue with their science into higher education and careers. (p. 112)

Influence of Pedagogical Practices

That scientific investigations have the potential to be instrumental in a budding scientist's life has already been seen, at least insofar as summer science internships are concerned. But is it possible to perform these scientific investigations *within* the time, space, and material constraints of the science classroom, and if so, what would they look like? In their study of 364 mathematics and science lessons using a structured observation protocol, the Horizon Research, Inc. implicated classroom teaching:

> Rather than advocating one type of pedagogy over another, the vision of high quality instruction should emphasize the need for important and developmentally-appropriate mathematics/science learning goals; instructional activities that engage students with the mathematics/science content; a learning environment that is simultaneously supportive of, and challenging to, students; and, vitally, attention to appropriate questioning and helping students make sense of the mathematics/science concepts they are studying. (Weiss, et al., p. 14)

The literature shows that "hands-on" activities, "laboratory based" experiments (the extensive use of using the laboratory to perform experiments and do activities), and the more comprehensive inquiry-based or problem-based learning environments (PBLE) ideally lend themselves to fulfilling these requisites. For example, Taylor, et al. (1999) painted a picture of this ideal learning environment: "Imagine a science classroom where hands-on learning is central, where examples and applications represent both genders, where interactions between the teacher and all students are respectful and supportive, and where science content is taught with passion and is perceived by all students to be relevant" (p. 35).

“Hands-on” activities, laboratory instruction, and inquiry and PBLE’s should not be thought of as independent strategies for teaching science but as overlapping approaches. For example, there are usually numerous “hands-on” opportunities in most laboratory activities. However, the latter can run the gamut from being “cookbookish” (perfunctory) to being open-ended, allowing for student creativity in the formation of the question and design of the procedure. Laboratory activities can also be based upon a problem dictated by the lab book or the teacher, or they can be the result of the student’s own query, and thus different from the research of everyone else in the classroom. Such blurred distinctions should be kept in mind as these three not-so-disparate pedagogies are reviewed.

An extensive annotated bibliography compiled by Lowery (2003) summarizes the research on hands-on science programs and so its citations will not be repeated here. This compendium is divided into three main sections. The first part recounts the historical efforts made by the National Science Foundation in the 1960’s to improve science education in the elementary schools. The theoretical perspectives for these approaches were based upon the thinking of Piaget, Robert Gagne, and Jerome Breuner. Assessments of these efforts showing measurable improvement compared to textbook/lecture programs were conducted over two decades later, and citations for these studies were included.

The second part of Lowery’s bibliography harks back to this chapter’s earlier comments on the influence of textbooks in science career persistence and includes a scathing review of the 4.5 billion dollar-a-year textbook industry. The researchers and studies he cites reported woefully inadequate and error laden textbooks that all too frequently were simplistic and formulaic, with an emphasis on facts and memorization rather than thinking and problem solving. Even when kits were attached, almost as an afterthought in deference to the “hands-on” movement, Lowery states:

> It is important to note that no studies exist that show that textbook or textbook-with-kit approaches improve students in any way… Textbook approaches emphasize memorization and recall of facts, more than half the activities/experiments do not work… In general, studies have found that at the elementary level, the content is often beyond the cognitive capacity of the students; prerequisites (prior knowledge) needed for understanding are not part of earlier experiences; the instruction utilizes methods for teaching reading rather than methods for teaching science. (p. 15)

Another component of this second section of Lowery’s bibliography provides preliminary reviews of some twenty-three current NSF sponsored elementary and middle school science projects.

Findings from these studies parallel the findings of the summary studies conducted on the 1960s programs: Students learn and retain more content knowledge; students gain confidence in their ability to do science and solve problems; students improve in their language arts (reading, writing) skills; students’ attitudes toward science remain high; females have as much success as males. (p. 6)

The third part of Lowery’s bibliography reviewed the positive effect of hands-on science upon other subject areas – an important “spill-over” that is tangential to the focus of this dissertation. Suffice it to say that most of this research and study relates to elementary school education (and some middle school) and not to high school teaching practices. In addition, as has been the case in almost every study cited in this chapter thus far, effectiveness and impact were gauged by changes in attitude and achievement by students shortly after the intervention.

Whether or not these changes contributed to persistence in science as a career was not determined, e.g., with a longitudinal study.

One longitudinal study that was conducted (but ended after high school), however, reinforces the consensus that giving more attention to developing positive attitudes towards science at least will promote ongoing participation in science. After observing that numerous studies report a generally declining attitude and interest in science as students matriculate through their middle and high school years, George (2003) concludes that:

> On the other hand, research has shown that students retain positive attitudes toward science in general and consider science to be useful and relevant in their daily lives. Given this distinction, science teachers need to find more creative ways to present science subjects in the classroom in order to maintain interest for science subjects. (p. 447)

Laboratory activities and experiences are an excellent forum for generating interest, as the next article indicates.

In an expansive study of twenty ninth-grade physical science classes during the course of a year, Freedman, (1997) “investigated the use of a hands-on laboratory program as a means of improving student attitude toward science and increasing student achievement levels in science knowledge” (p.343). Attempting to discern the relationship (cause and effect vs. correlation) between the laboratory experience, student attitude towards science, and student achievement in science (and perhaps persistence in science by implication), Freedman comments:

> The search for a viable model of science instruction that will increase student achievement in science has become a global agenda. Investigation continues in an effort to determine what the factors are in science instruction that foster student achievement in science. The model of instruction which appears to be gaining support is that instruction

> which promotes a positive attitude toward science will improve achievement. The laboratory, as a factor in the learning environment, is intrinsic in the development of positive student attitudes toward science. (p. 344)

Freedman's study did indeed support this model.

Two researchers who figure prominently in the ongoing effort to explicate the impact of the laboratory in science education are Hofstein and Lunetta. Since their original review in 1982, they note significant change:

> The science education community has substantially expanded knowledge of students' understanding of science concepts and of the nature of science. There has also been a substantial paradigm shift in thinking about the ways in which learners construct their own scientific knowledge and understanding. In addition, substantive developments in social science research methodologies enable much richer examination of laboratory and classroom processes and of students' and teachers' ideas and behaviors. Furthermore, throughout the past 20 years the exponential growth of high-technology tools has powerful implications for teaching, learning, and research in the school laboratory. (Hofstein and Lunetta, 2003, p. 30)

In other words, even though there is overlap between "hands-on" activities, laboratory experiments, and PBLE's, in order for them to be effective in promoting interest in science (and therefore subsequent improvement in students' attitude and achievement, and, ostensibly, persistence in science), the insights into how students learn and the incorporation of ever-emerging technologies are imperative.

PBLE's in particular succeed on several fronts – they are authentic, they engender community, they foster metacognition, and they generate artifacts. In short, they provide the necessary ingredient to bridge the gap between mastery and appropriation – motivation. How PBLE relates to “mastery to appropriation via motivation” will be the initial focus of the next part of the literature review, followed by an examination of those studies which investigate the nature and success of PBLE’s themselves.

As just stated, a key ingredient in transitioning students from the “what” (knowledge – naïve or mastery – that students bring to the classroom or have been formally taught) to the “so what” (appropriation, i.e., personal ownership) and someday to the “now what” (integration and life-changing), is motivation. (see Polman, (2000), p. 1 and (2001), p. 3 for a further discussion of the terms “mastery” and “appropriation” and “motivation;” appropriation is also discussed by Laffey & Espinosa, 2003, p. 1.) It is the conviction of these researchers that inquiry-based learning projects, grounded in cognitive science and supported by appropriate technology, create PBLE’s that are inherently motivational and will thus promote learning science. Blumenfeld (1991) puts it this way:

> Project-based learning is a comprehensive perspective focused on teaching by engaging students in investigation. Within this framework, students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artifacts. (p. 371)

Simply stated, students are learning science best when they are doing what scientists do. As O’Neill and Polman (2004) frame it, “What is more scandalous than students’ lack of knowledge of specific science content or process is their lack of understanding of scientific practice: that is, why scientific research is done and how it is accomplished.” (p. 236).

The historical underpinnings for PBLE can be traced back to Dewey, but a recent reworking of its principles according to cognitive science has resulted in a resurgence of sorts, as is apparent by the numerous references in the literature. Though only a few can be mentioned here (see Sadler and Tai, (2001), Von Secker and Lissitz, (1999), and an entire case study by Polman, (2000)), the overall consensus is "Involving students in processes of inquiry that include the planning of long-term, empirical research has unique and demonstrable benefits compared with the conceptual coverage for which precollege science education typically strives" (O'Neill and Polman, p. 262).

The first hallmark of PBLE is *authentic inquiry*, and is best defined by Hofstein and Lunetta (2003):

> *Inquiry* refers to diverse ways in which *scientists* study the natural world, propose ideas, and explain and justify assertions based upon evidence derived from scientific work. It also refers to more authentic ways in which *learners* can investigate the natural world, propose ideas, and explain and justify assertions based upon evidence and, in the process, sense the spirit of science. (p. 30)

The authenticity (and subsequent motivation) derives from the fact that it is the answer to the students' own question they are pursuing – an example of appropriation.

The second hallmark of PBLE is it emphasis on *metacognition*, or understanding how one learns. In order for this to happen effectively, students need to be able to test their own ideas and conceptions and get feedback from peers, mentors, or scientists, something imminently feasible with modern technology. Appropriation is more likely to result when students discover or correct an understanding for themselves, as opposed to being told by their teacher.

A third hallmark of PBLE has to do with its communal aspects – working not only as a team in order to answer a question, but often accessing other scientists or students anywhere in the world (or their stored understanding) by means of the internet. In a comprehensive book on this subject, Feldman, et al. (2000) reiterates “We now believe that it is critical to identify the classroom as the primary *community of learners* in which the dialogue among students takes place” (p. 17, italics added). Hofstein and Lunetta (2003) aver:

> The laboratory offers unique opportunities for students to engage in collaborative inquiry and to function as a classroom community of scientists. Such experiences offer students opportunities to consider how to solve problems and develop their understanding. Through collaboration, they can also come to understand the nature of an expert scientific community. (p. 36)

The last hallmark is *artifacts*, and its significance cannot be underestimated, according to Blumenfeld, et al. (1991):

> Students’ freedom to generate artifacts is critical, because it is through this process of generation that students construct their knowledge – the doing and learning are inextricable. Artifacts are representations of the students’ problem solutions that reflect emergent states of knowledge. Because artifacts are concrete and explicit (e.g., a model, report, videotape, or computer program) they can be shared and critiqued. This allows others to provide feedback and permits learners to reflect on and extend their emergent knowledge and revise their artifacts. (p. 372)

Once again, the artifact created by the students, like the knowledge it represents, is authentic, unique, and their own - the very ingredients that turn concepts into mastery, and mastery into appropriation. It is worth noting that the entire learning process is scaffolded by the effective integration of technology, a subject mentioned earlier. The question remains, however, as to whether or not motivation-based appropriation through the effective use of pedagogies such as PBLE's succeeds to the point of persistence in scientific careers.

In summary of this major portion of the literature review, it is apparent that the many components of high-school science-related experiences that *may* significantly influence science career persistence are synergistic. Excellent teachers and mentors, access to technology and other resources, and participation in "real" science, both in the classroom through pedagogical practices like PBLE's or summer research programs, promote heightened interest and positive attitudes towards science and science careers. These in turn can lead to the perseverance necessary to stay the course through challenging courses and rigorous internships. As Stakes and Mare (2001) have observed:

> These findings provide strong support for the preparedness model of program impact. Clearly, students who entered the program with more science advantages – previous science enrichment experience, strong support from family and teachers, a positive teacher model, and confidence in their abilities – appeared to profit more from the science programs. Our results provide evidence of the value of a history of positive science-related experiences for continued growth in commitment and confidence to achieve in the challenging world of science. (p.1082)

Influence of Mentors/role Models

Good teachers are, among other things, mentors, but not all mentors are teachers – at least not in the sense of the professional teacher. Others who often play the role of mentor, as listed by Byrne (2000, p. 23-26), include family members, peers and playmates, business/industry mentors, and popular mentors (e.g., Bill Nye the Science Guy, James Escalante, Carl Sagan).

The focus at this stage, however, will be on scientists who have entered into any of a number of different kinds of programs that pair students and scientists together in a more than superficial fashion, such as summer programs and apprenticeships.

One other point about mentors is pertinent. A mentor is often part of a larger intervention, such as a science fair project or a summer internship. Consequently, it is often difficult to separate the effect of the mentor from the effect of the intervention when ascertaining the success of either. In fact, as the literature shows (Bell, et al., 2003, p. 500; Marsa, 1993, p. 2), the success of these programs is predicated upon an excellent mentor/student relationship. This section will look exclusively at the influence of mentors (excluding science teachers) since the influence of projects and internships – as much as they can be extricated from a mentor – has already been surveyed.

A mentorship (partnership, apprenticeship, collaboration) is a relationship that takes time, intent, and energy – something that not all scientists are able or willing to give. As noted by Bloom in his book *Developing Talent in Young People* (1985), "No matter what the initial characteristics (or gifts) of the individuals, unless there is a long and intensive process of encouragement, nurturance, education, and training, the individuals will not attain extreme levels of capability in these particular fields" (Marsa, 1993, p. 2). This relationship contains the essence of a "community of practice" as described by Barab and Hay (2001, p. 71).

The job of mentors, if they are going to do it right, is substantial, especially in conjunction with their heavy research/teaching load: "Mentors were responsible for guiding the apprentices' acquisition of background knowledge, establishing the research framework for the apprenticeship projects, and providing day-to-day guidance and troubleshooting" (Bell, et al., 2003, p. 500). A more detailed discussion of mentorship and the phases the participants go through is found in Feldman's study (2001) of 21 graduate students in a graduate genetics program.

The influence of mentors can be profound and is especially evident in the studies of the many programs designed to increase women and minority participation in science. After talking to dozens of minority science students in high school through graduate school, Culotta (1992) recorded that effective mentors pushed students to persist and encouraged them not to be satisfied unless they did well. In addition, "Many young minorities say it's important to see successful scientists of their own race and even gender" (p. 1212). Cavallo, et al., (1999) in their review of the literature, reported that mentors do not even have to be of the same ethnicity (p. 295).

A program called *Sisters in Science* was evaluated by Hammrich (1997). Comprised of a science program, learning program, and summer camp, *Sisters in Science* was

> an intergenerational program, [in which] retired women and women currently working in the science, engineering, and mathematics fields, as well as female university students who are pursuing careers in science and science education, serve as role models for the girls and share life and work experiences. (p. 2)

The preliminary indications showed a "positive pattern of change in the girls' science, math, and language skills" (p. 3). A two week residential program for high-achieving eighth-grade girls that was studied by Jayaratne, et al., (2003) was less conclusive because of difficulty in separating other factors of the program from the effect of role models. Evans and Whigham (1995) looked at a role model intervention project that involved 964 Iowa girls and boys in 57 ninth-grade classes. They found it to be effective in changing attitudes towards science, math, and technology – especially for girls.

Another benefit of a mentor/role model was briefly mentioned in a different context earlier in Abraham's study (2002) of an apprenticeship program but bears repeating here. When the mentor is a scientist, the aura and mystique surrounding what scientists do that is often a barrier to persistence according to the literature is removed:

> Analysis of students' open-ended responses clearly indicates that participation in the program had a profound effect not only on their understanding of and affinity for science and science related ventures, but also in perceptions of the work of scientists… The analysis supports the idea that participation in the program encourages students to look toward science majors and careers. Any method by which this interest can be supported and nurtured would assist in the retention of eager students in the sciences. (p. 231)

In drawing this section to a close, the following observation unites the benefits of role models with the kinds of research internships mentioned earlier.

> Rather than "telling" learners about a discipline, apprentices are immersed within a community in which they engage in practices "at the elbows of more competent peers, experts, or old-timers." This is consistent with the recommendations of science educators who have advocated for active learners doing scientific investigations, instead of passive learners receiving science instruction. (Barab & Hay, 2001, p. 71)

Conclusion

As has been repeatedly observed, the voice that is missing from the myriad of studies and programs cited thus far are the scientists themselves. Several researchers, however, did ask the only ones who could truly know, as these last three reports attest.

Characteristic of one of the approaches that will be used to gather data for this research is the biographical sketch, a technique used by Morgan (1996) in her account of Dr. Billy Joe

Evans, a chemistry professor at University of Michigan. Evans relates, “As a young boy I played with model airplanes, gasoline engines, rubber bands and electric trains” (p. 22). These activities – plus mowing the grass (!) during which times he “experimented with different ways of making customers’ lawns look green and prosperous, thus learning a little bit of the scientific method” (p. 22) – set the stage. Then, “I had a good high school chemistry teacher, George Espy, a Morehouse graduate, who gave me an enthusiasm for science” (p. 22).

Another approach that is sometimes used is the poll, such as when Roper Starch Worldwide, sponsored by the Bayer Corporation, mailed questionnaires to 2,500 members of AAAS (American Association for the Advancement of Science). As reported by Lawton (1998), the 1,435 Ph.D. holders who responded had much to say about science education. For example, some said that “they would approve of the inquiry-based, hands-on approach” though others “would also like to see a continuation of some traditional methods of teaching and learning, particularly for high school students” (p. 1). Seventy percent said that the high school curricula should have “a lot” of “teachers acting as guides and mentors instead of lecturing; students carrying out experiments and formulating their own results; and students thinking critically, testing assumptions, and questioning common opinion” (p. 1). However, none of the responders was asked specifically what experiences were instrumental in his/her own career persistence.

The last approach, and the one most similar to the aim of this paper (but with a narrower focus), was a survey (Rowsey, 1997) of thirty-five research scientists “regarding the effect of teachers and formal schooling on their decisions to become scientists” (p. 20). These scientists, selected randomly from an original pool of 85, were predominantly male (33), ranged in age from 28 to 65, attended high schools in 21 different states, and practiced primarily in the physical sciences (22) as opposed to the biological sciences.

By the time they had graduated from high school, 85% reported a special interest in science, and 33% had made a career commitment to science. Thirty-seven percent indicated that they had been positively influenced by a family member, and "43% reported that at least one high school science teacher had influenced them" (p. 21). Only 22% reported that any special "event" (science show, laboratory activities, demonstrations, special courses or field activities) in high school was a positive influence. Finally, 37% responded that historical or current events, such as the ecological movement, the launching of Sputnik, moon exploration, the space shuttle, and advancements in molecular biology) were influential during their formative years.

From this data Rowsey garnered the following observations: For those scientists for whom such factors were influential, it was because teachers were "enthusiastic" and "involved the class in science 'activities'" (p. 23). Demonstrations, laboratories, field trips, and experiments figured prominently for those scientists positively influenced by special pedagogical approaches. Lastly, at least for some of the scientists,

> It is interesting to note that chance happenings of events that occurred during the subjects' formative years had a greater influence on their career choice than activities that could have been planned and carried out as a part of the school science curriculum. (p. 23)

Rowsey's study provided a foundation that can be built upon, and a direction to be pursued. A personal interview affords a richness and depth of response, as well as the flexibility of follow-up, that a five question survey (e.g., Bayer Corporation's) does not permit. In addition, a qualitative study is more probative and can both jog memory and elicit subtle shades of heartfelt meaning. Finally, even though Rowsey reported many of his findings as percentages, there can be no expectation that these quantitative values are characteristic of the population of scientists at large (and therefore beneficial for determining policy) since no effort was made to determine if the original population was truly a random sample. A qualitative study, however, can provide a broad spectrum of insights that can inform both future research and decision-making. This is the goal of Chapters Four and Five.

CHAPTER 3

Methodology

Introduction

Scientists represent a subset of students who have persisted in science to the point of making it their career. During the course of their lives leading up to their professional practice, they have been exposed to varying degrees of science-related experiences both inside and outside the classroom walls, and within and outside the normal school day. A review of the literature of persistence studies of students in science at these various levels reveals two shared characteristics.

The first characteristic is that the evaluations of the extent of these science-related influences were almost always quantitative. Simpson and Oliver (1990) commented on the difficulty, if not inadequacy, of this approach:

> It earlier was hoped that a model (or models) could be synthesized that would depict precise mathematical relationships along with important qualitative dimensions. As the research team analyzed and synthesized the major components of the longitudinal study, it became obvious that no parsimonious mathematical formula was going to emerge. The methods were so varied and the number of variables so numerous that final formulation of a summary model eventually rested upon the combining of smaller quantitatively derived conclusions with important components emanating from qualitative sources. (p. 14)

The second characteristic is that these studies almost exclusively polled the students themselves during or shortly after their experience but well before entering the scientific workforce. In other words, student evaluations were frequently confined to the choices of words or phrases pre-selected for them in a questionnaire or survey. Often their evaluation was limited to performance on aptitude or attitude tests, neither of which necessarily guarantees or predicts that the students will persist in science. Even more significant is the missing testimony of the scientists themselves. Students, even if they have persisted into college, are not yet practicing scientists in the fullest sense of the term. It is the voice of the experienced professional scientist that is missing in the dialogue about how to improve the quality of high school science education in this country and thereby increase the number of potential scientists in the professional pipeline.

Towards this end, I report on the responses of professional scientists, allowing them unfettered expression of those high school science-related experiences that may have played a role in their science career. To accomplish this, I will employ a qualitative approach, specifically the case study. As defined by Denzin and Lincoln (2000):

> Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world.…qualitative research involves an interpretive, naturalistic approach to the world....qualitative researchers study things in their settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them. (p. 3)

There are numerous qualitative approaches, each with their own particular strengths and advantages. Creswell (2003), who also defines qualitative research, enumerates the different approaches:

> A qualitative approach is one in which the inquirer often makes knowledge claims based primarily on constructivist perspectives…or advocacy/participatory perspectives… It also uses strategies of inquiry such as narratives, phenomenologies, ethnographies, grounded

> theory studies, or case studies. The researcher collects open-ended, emerging data with the primary intent of developing themes from the data. (p.18)

Because each scientist brings with her/him a unique history of events leading up to an entrance into the professional scientific community, the case study is deemed the most appropriate method to discover those factors that significantly influenced each of them. This is what Shank (2002) calls the cumulative case study in which "a single topic is examined through the perspectives of many different case samplings. A single complex case is built by selecting and ordering individual cases" (p. 55). Shank further explains why this qualitative approach should yield insights into "why" and not just "what" factors influenced scientists:

> These cumulative case studies differ from surveys, though, in the fact that each new case is deliberately added to make the overall picture richer, deeper, and more complex. In a survey, we would look for patterns of how people might typically react. In the cumulative case study, we have instead an exploration of options. (p. 56)

This "exploration of options" will hopefully divulge the nature and degree of impact of the science-related factors that influenced the scientist in each of the case studies.

A further delineation of the case study is laid forth by Berg (2001): "Explanatory [as opposed to exploratory and descriptive] case studies are useful when conducting causal studies. Particularly in complex studies of organizations or communities, one might desire to employ multivariate cases to examine a plurality of influences" (p. 230). In other words, a cumulative and explanatory case study is a potentially effective means to discover common reasons (causes) for why different scientists entered the scientific community.

Perspective

Before proceeding to the next section that will, in part, describe my relationship to the scientists being interviewed and my vested interest in the results of the study, it is important to situate myself in this research in terms of my perspective and "world-view." I believe that there is Truth and Objective Reality, and that they are inherent, i.e., created, in the Universe. I also believe that researchers, using both qualitative and quantitative approaches, are capable of discovering bits and pieces of that Truth/Reality. However, I am not a positivist.

I say this because I believe that we can never successfully use these or any human methods to "prove" what is true/real and what is not. The reasons for this are because (1) all researchers and scientists are finite and thus our methods are as well; (2) all researchers and scientists are fallible and thus our methods are as well; (3) all researchers and scientists are a part of and therefore affect the very phenomenon they study; (4) nature, especially human nature, is so profoundly complex that mere human interrogations and studies can never fully fathom it. Is it any wonder we so meticulously subject our research to peer review and reproducibility and verifiability?

In other words, our inability to conclusively demonstrate beyond the shadow of a doubt that the results of our research are "true" is not because there is no such thing as Truth, or that Truth is relative, or because everyone constructs his/her own Truth, but is because of these four natural limitations that I have just identified. (Obviously I am not a pragmatist, relativist or postmodernist either.) Yet the good news is that our research and discoveries can make a difference and positively influence lives and improve the human condition. Towards this end I press on. I am a "narrative realist." The two elements of this hybrid are elucidated shortly.

Sources of Data

Primary Source of Data

The principle source of data will be the interviews with scientists. As should already be apparent from my choice to make scientists I know the objects of my case studies, I will not be the so-called unbiased or disinterested interviewer. This is hardly novel, nor is it necessarily a liability. As Fontana and Frey (2000) observe, “Increasingly, qualitative researchers are realizing that interviews are not neutral tools of data gathering but active interactions between two (or more) people leading to negotiated, contextually based results” (p. 646).

Interviews can run the gamut from being entirely prescribed to totally unstructured. A cursory look at the two components of the questionnaire (Appendix A) will reveal that my interviews will be situated between these two extremes, as described by Berg (2001):

> Located somewhere between the extremes of completely standardized and completely unstandardized interviewing structures is the semistandardized interview. This type of interview involves the implementation of a number of predetermined questions and/or special topics. These questions are typically asked of each interviewee in a systematic and consistent order, but the interviewers are allowed freedom to digress; that is, the interviewers are permitted (in fact expected) to probe far beyond the answers to their prepared and standardized questions. (p. 70)

How these questions will be used and when they will be asked during the course of the interview is outlined later in the chapter.

Nevertheless, I do not want to fall prey to what Fontana and Frey have observed: “There is inherent faith that the results are trustworthy and accurate and that the relation of the interviewer to respondent that evolves in the interview process has not unduly biased the account" (p. 646). This is what has led to the "stubbornly persistent romantic impulse in contemporary sociology: the elevation of the experiential as the authentic." (Silverman, 2000, p. 823). Consequently, the interviews will be further situated within both the narrative approach, as explained in the next quote, and the realist approach, as unpacked in the subsequent paragraph.

> Interview data [accesses] various stories or narratives through which people describe their worlds….This narrative approach claims that, by abandoning the attempt to treat respondents' accounts as potentially "true" pictures of "reality," we open up for analysis the culturally rich methods through which interviewers and interviewees, in concert, generate plausible accounts of the world. (Silverman, 2000, p. 823)

How the interviews incorporate the realist approach lies in the extent to which the data can be corroborated both internally and externally. Internal corroboration occurs (1) if and when similar high school science-related influences are repeatedly cited by different scientists/interviewees; and (2) through *content analysis* and is discussed in the next paragraph. External corroboration, which will be discussed in the next section, is also subject to content analysis and results if other sources of data reveal the same themes.

The three approaches to content analysis according to Berg (2001) are interpretative, social anthropological, and collaborative social research. The second of these aptly situates me within the research framework, as is evident from Berg's description of researchers who use this technique:

> In order to accomplish data collection, they have necessarily spent considerable time in a given community, or with a given assortment of individuals in the field. They have participated, indirectly or directly, with many of the individuals residing in or interacting with the study population. This provides the researcher with a special perspective on the

> material collected during the research, as well as a special understanding of the participants and how these individuals interpret their social worlds. (p. 239)

After all, I have spent twelve summers working in the same laboratory building as most of the scientists who were interviewed. This also reinforces the appropriateness of using a qualitative approach.

Secondary Source of Data

A subsidiary source of data will be primarily autobiographical material available in libraries and online. Its purpose will be for external corroboration, often referred to as *triangulation* (though this term is sometimes used for the process of internal corroboration as well), and is accomplished through both content analysis and member checking. When content analysis is applied to external corroboration, the approach is interpretive, and has the advantage in that it can be "used nonreactively: no one needs to be interviewed, no one needs to fill out lengthy questionnaires, no one must enter a laboratory. Rather, newspaper accounts, public addresses, libraries, archives, and similar sources allow researchers to conduct analytic studies" (Berg, 2001, p. 258). In addition, it is cost effective, and biographies of scientists from all over the world and from past centuries can be inspected.

This method, however presents a serious challenge according to Berg:

> The single serious weakness of content analysis may be in locating unobtrusive messages relevant to the particular research questions. In other words, content analysis is limited to examining already recorded messages. Although these messages may be oral, written, graphic or videotaped, they must be recorded in some manner in order to be analyzed. (p. 259)

An initial check of library and internet resources indicated that accessing autobiographical material about scientists would not be a problem. Several oral histories were located, and one in particular (http://www.chemheritage.org/exhibits/ex-nav2.html) defined itself:

> An oral history is a structured conversation on tape that attempts to construct an "orchestrated autobiography" of the narrator. Oral histories often treat broad topics in an individual's life—family background, childhood, education, factors influencing career decisions, and the work history itself—or they may focus on a few key episodes in the individual's career. Oral history interviews explore the development of organizations, moments of innovation, and the growth of ideas in ways rarely found in secondary source materials or in other formal, printed communications. The results are intended to be part of the historical record and available for future use. (Young, 2005, p. 1)

The thoroughness with which the high school experiences of scientists were discussed, however, presented somewhat of an obstacle, since the focus of these sources was on their post-graduate experiences and their present research, rather than their high-school science related experiences.

Berg also presents a healthy reminder about an important limitation of content analysis (when the narrative approach is employed) when he declares that:

> It is ineffective for testing causal relationships between variables. Researchers and their audiences must resist the temptation to infer such relationships. This is particularly true when researchers forthrightly present the proportion or frequency with which a theme or pattern is observed. This kind of information is appropriate to indicate the magnitude of certain responses; however, it is not appropriate to attach cause to these presentations. (p. 259)

This is, after all, a qualitative study looking for rich data, thick description and depth in understanding and insight.

The second way in which external corroboration will be accomplished is through "member checking" (Creswell, 2003) – allowing the scientists who have been interviewed to review both the transcript of their own interview as well as the final draft of the dissertation before it is submitted. In this way they can clarify or even retract statements, provide context or amplification, and validate the fairness and accuracy of the discussion.

Sample

Because of my somewhat unique background in both education and science (as explained later in this section), and the science background and educational interest of the interviewees, the words of Waldrop (2004) ring true: "During this dynamic and continually evolving process, the participants' unique experiences and the researcher's individual perspectives converge. Knowledge and understanding emerge from what the researcher does, learns, and experiences in this context" (p. 244).

In one respect, the scientists that I will interview are members of a convenience sample in that I have an ongoing, though often sporadic, relationship with them through my involvement in several science research and science education organizations. For example, in my role as a researcher at the Idaho National Engineering Lab (INEL) for the last 12 summers, I have met scores of scientists and become good friends with many of them. Another example stems from my role as a teacher of high school science for 30 plus years. Not only have I met colleagues who have come to the teaching profession following a career as a research scientist, but I also have had some students whose parents were scientists.

In a different respect, however, the scientists I will interview, though certainly not a random sampling, will be more than just a convenience sampling. To use the terminology of Berg (2001), “This category of sampling is sometimes called *judgmental sampling*. When developing a purposive sample, researchers use their special knowledge or expertise about some group to select subjects who represent this population” (p. 32). In other words, precisely because of my ongoing relationship with these scientists, I will be able to be particularly alert to, and attuned with, those scientists who have reflected upon and expressed concern for high school science education. Piantanida and Garman (1999) describe this artfully when they state, “Rather than assuming the traditional stance of a detached and neutral observer, an interpretive inquirer, much like a tuning fork, resonates with exquisite sensitivity to the subtle variations of encountered experiences” (p. 140).

These friendships and acquaintanceships also afford me the opportunity to ask them personally about the choices and influences that led them to a career in science. (Indeed, without exception, every scientist that I have asked in my preliminary tests of the research question, questionnaire, and interview process was interested in the subject of this study, excited to tell her/his own story, and willing to participate in the research.) The challenge will be to select as diverse a group as possible from the large pool of available scientists. In particular, I will include women and minorities disproportionately in my sample in order to shed some light, hopefully, on reasons why they are under-represented and how they were encouraged to persist.

Procedure

The instrument I will use to initiate the interview is a questionnaire (see Appendix A) with two components. The first part is a survey requesting the usual demographic information, and the second will be a series of three open-ended questions (*numbered* in the appendix) relating to their science-related experiences in high school. Each scientist will be provided a copy of the instrument, probably by email, and asked to fill out the survey information and reflect on the three questions. Then, at a mutually convenient time and place, I will arrange an interview. After asking her/him to read and sign the informed consent document (see Appendix L), I will tape the responses to both the three open-ended questions and my follow-up questions (including the *lettered* questions in the appendix).

The follow-up questions are more specific and thus are not initially provided. In this way they will not influence or direct each scientist's responses along any particular line of thinking. Their purpose will be to expound (if necessary) on some of the educational terms used in the original three questions, to jog memory, and to help focus the interview on some of the possible factors that may have influenced them, consistent with the semistandardized interview. Following each interview, the tape will be transcribed by a third person. After numerous readings of the transcriptions and incumbent reflection, the prerequisite coding will commence.

Data Analysis

Ryan and Bernard (2000) describe coding as:

> The heart and soul of *whole-text analysis*. Coding forces the researcher to make judgments about the meanings of contiguous blocks of text. The fundamental tasks associated with coding are sampling, identifying themes, building codebooks, marking texts, constructing models (relationships among codes), and testing these models against empirical data. (p. 780)

Discovering these themes, according to Berg (2001), is straightforward:

> To begin, you simply seek naturally occurring classes of things, persons, and events, and important characteristics of these items. In other works, you look for similarities and

> dissimilarities – patterns – in the data. But you must look for these patterns systematically! (p. 103)

Shank (2002) expounds on what “systematically” means:

> Thematic analysis, first and foremost, is about searching for patterns in data. When we find a pattern, then we have good reason to suppose that something systematic is creating that pattern. Another name for such a pattern is, of course, a theme. When observations pile up, and a theme seems to suggest itself to the researcher, thematic analysts say that these themes seem to “emerge from the data.” (p. 129)

Finally, Shank clarifies a common misconception:

> In short, themes do not really emerge from the data. What emerges, after much hard work and creative thought, is an awareness in the mind of the researcher that there are patterns of order that seem to cut across various aspects of the data. When these patterns become organizationed, and when they characterize different segments of data, then we can call them “themes.” (p. 129)

(Some of these patterns have already begun to become “organizationed” as a result of the perusal of the transcripts of some preliminary interviews that were conducted earlier and subjected to peer review as a part of a graduate class in qualitative analysis. Of course, should any additional themes become evident as the interviews progress, they will be investigated in subsequent interviews).

Next, each transcription will be color-coded with highlighters according to the various emerging themes (see appendix B). Finally, those words, phrases, and sentences that are part of each theme will be grouped together and evaluated, consistent with the initial steps of the format suggested by Miles and Huberman (1994):

1. Affixing codes to a set of field notes drawn from observations or interviews;
2. Noting reflections or other remarks in the margins;
3. Sorting and sifting through these materials to identify similar phrases, relationships between variables, patterns, themes, distinct difference between subgroups, and common sequences;
4. Isolating these patterns and processes, commonalities and differences and taking them out to the field in the wave of data collection…;
5. Gradually elaborating a small set of generalizations that cover consistencies discerned in the database;
6. Confronting those generalizations with a formalized body of knowledge in the form of constructs or theories. (p. 9)

Through this process the richness and diversity of high school science-related experiences that contributed to the persistence in science careers can emerge. This in turn can inform those who are involved in the enterprise of nurturing and directing high school science education.

CHAPTER 4

Findings: What the Interviews Say

Introduction

In the same year that Harry S. Truman signed into law the National Science Act, thus creating the National Science Foundation (see the introduction to Chapter 1), a well-known clinical psychologist was in the midst of a seminal study that would independently shed light on some of the related issues that instigated the passing of this legislation. Anne Roe (1952) begins the account of her investigation by declaring, “This is the story of four years of research on the most fascinating problem in the world, - at least it seems so to me. The problem is what kinds of people do what kinds of scientific research and why, and how, and when” (p. 1).

Using a mixed-methods approach, Roe reported on her interviews and testing of 64 of the most eminent U.S. biological, physical, and social scientists of her day. These subjects, as selected by panels of their peers (some of whom were themselves part of the study), were relatively evenly divided between these three branches of science, were men (“in order to eliminate variation due to sex,” p. 22) between the ages of 31 and 61, and were actively engaged in research.

The next two chapters (and, in general, this dissertation), can be considered a companion study and a half-century follow-up to Roe’s work, but are quite different in a number of significant ways. In some respects they are broader in scope by including the stories of women scientists, as well as the stories of more typical scientists who labor faithfully and productively in their pursuits but have not necessarily gained national prominence. In other respects they are narrower in scope because they exclude social scientists, and focus particularly on the influence of high school science-related experiences. Finally, these chapters are overwhelmingly qualitative reports of the findings, and draw no more than surface statistical conclusions from any demographics, tables, and charts.

Organization

The two chapters are divided as follows: Chapter Four ("What the Interviews Say") contains both a demographic description of the scientists who were interviewed and their responses to the interview questions (see Appendix A) and the follow-up questions (see Appendix C). Chapter Five ("What the Autobiographies Say") encompasses a variety of extant but diverse sources including Roe's aforementioned *The Making of a Scientist*, biographical sketches of famous scientists (many of whom were/are Nobel laureates) from several books and websites, and an online oral archive containing the self-reporting of the experiences of women scientists.

The purpose of these two chapters is not to compare the biographies to the interviews, nor is it to contrast the experiences of men scientists with women scientists, though some of that might be possible. Instead, the goal is to provide as rich and diverse a mosaic as is reasonably possible about those high school science-related experiences that have influenced scientists. There is no "one size fits all" or recipe that, if the proper experiential ingredients are mixed, will result in a fully functional scientist.

Towards this end, there is a plethora of quotes. In a simplistic way each quote in a qualitative study is analogous to a number or datum in a quantitative study. The difference, however, is that unlike a number, each quote is highly personalized, contextualized, and nuanced and thus contributes to the multi-hued painting or textured fabric that is human experience. (Some technical notes: Whenever the scientists use specific names of former teachers, only their first initials will be given. The letters at the end of each quote refer to a particular scientist, and may be cross-referenced by the reader against the spreadsheets in the Appendix K in order to learn more about each scientist. Lastly, italicized sentences within quotes are the researcher's questions.)

The Scientists

Thirty-two scientists were interviewed for this study. Each is a research scientist who indicated an interest in the focus of this investigation. Most were chosen because that interest was identified or overtly expressed to the author at some point in an ongoing relationship. The rest were recommended by their colleagues because of their professed interest and thus came into the study via referral.

Some care was given to selecting a cadre of scientists with a broad range of backgrounds, ages, and scientific specialties. As such, they represent the biological sciences (e.g., medicine, biotechnology, microbiology, genetics, molecular biology, environmental remediation), the physical sciences (e.g., physics, optics, analytical chemistry, surface chemistry, organic chemistry, pharmacology, toxicology) and the earth sciences (e.g., hydrology, soil science, materials science). Of course, because of the integrated nature of science itself, and the fact that most scientific research is to a large extent directed towards overcoming challenges that are innately multidisciplinary (i.e., applied, as opposed to purely theoretical), these categories are very loose and there is extensive overlap.

The interviews were conducted in two locations. Some of them took place in the St. Louis metropolitan area where the author lives and teaches. The majority occurred at the Idaho Research Center (IRC) that is located in Idaho Falls, Idaho, where the author has participated in various educational and research programs for a dozen summers. The IRC is part of the much larger Idaho National Lab (INL, formerly the Idaho National Engineering Lab), and is operated by the United States Department of Energy. (This explains the predominant western representation of both high schools and graduate schools that will be seen later.) More importantly, because the IRC is a research facility within a national laboratory (INL) that supports a broad cross-section of scientific disciplines involving a myriad of research projects, each requiring the input from multiple scientific specialties, access to scientists with very diverse specialties was possible.

Demographic Overview of the Scientists

The ages of the scientists (mean: 45.3) span three decades, including three in their early thirties and one in his early sixties. The distribution of these ages is very similar to the national distribution (National Science Board, 2004). All of the scientists are, or have been, involved in research and publication in their chosen fields. Those few (four) who do not have doctorates are so experienced in their fields and have demonstrated such interest in education that they routinely lead investigations and direct undergraduate students.

A little more than one-fourth (28.1%) of the scientists are females, slightly higher than the national average of 24.7% female representation in the sciences (National Science Board, 2004). Of these, the percentage in the biological sciences is typical of the national average (about half of degreed biologists are female) while the number in the non-biological sciences, though small, exceeds the national average. Twenty-five of the scientists were Caucasian, four were African-American, one was Hispanic, one was Asian, and one was Native American. As a point of reference, the science/math/engineering workforce in the U.S. is 3.4% African American, 3.1% Hispanic, and 0.3% Native American (Bonous-Hammarth, 2000).

When asked to assess the socioeconomic status (SES) of their family upbringing, the scientists fell into a somewhat bell-shaped distribution, with three in the lower class, six in the lower-middle class, thirteen in the middle class, and four in the middle-upper class. The minority scientists represented each of these four categories as well. No scientists reported an upper class background.

Of the 30 scientists who divulged their parents' occupations, eighteen came from homes where at least one parent was either a teacher, had some science-related training, or was employed in a science-related field. These professions included a biology teacher, a math teacher, two chemists, two physicians, three nurses, three engineers, two physicists (both were also university professors), a forester, a psychologist, a mother with some nursing training, and a father who worked at a national laboratory but not as a scientist. Additionally, one parent was an auto mechanic, one parent worked construction, and three parents were farmers – all occupations which afforded their children the opportunity to tinker, build, and repair things (i.e., hands-on experiences).

Except for four scientists who attended Catholic high schools and one who was home schooled during her senior year, the rest graduated from public schools, though one of the public schools was a science and math magnet school. Graduation-class sizes ranged from four that were 50 or less to six that were greater than 500. Almost a third of the high schools were located in rural parts of the country, one-fourth were classified as urban, and the rest were suburban. Only six of the scientists reported taking Advanced Placement (AP) courses in high school, and six mentioned that their schools didn't even offer them. Almost half of the scientists reported that their grades were predominantly A's, and about a third claimed grades that were a mixture of A's and B's. Except for one admission of grades that were D's, the rest declared grades that were generally B's.

Of the 27 scientists who commented on their laboratory facilities in their high schools, four of them ranked them as poor (minimal, limited, countertops only) and only six ranked them as excellent (good, modern). Six described their labs as being separate from their classrooms, five said they had combined classroom/labs, and the others referred to them as standard, regular, or typical. Four of the scientists recalled doing labs less than once a week, eight estimated weekly, and nine said more than once a week. Whether they distinguished between labs and activities is unknown. Seven of the scientists commented that their science teachers did few demonstrations, while twice that many felt that their teachers performed “lots” of demonstrations.

The average number of science courses taken during high school was three. One scientist only took one science course and three took as many as five. Only five scientists did not take any biology, only four did not take any chemistry, and only five did not take any physics. Twenty-three of the scientists took at least one level of each of the three main sciences – physics, chemistry, and biology. Ten of the scientists reported taking honors, advanced, or Advanced Placement (AP) courses. Other courses included general science, earth science, human anatomy and physiology, research methods, and biochemistry. All but one of the scientists had at least one science course during high school that was foundational to their eventual major and primary research focus.

Almost half of the high schools from which the scientists graduated were located in the west (California, Colorado, Idaho, Montana, New Mexico, Oregon) with the rest scattered over the Midwest (Illinois, Indiana, Iowa, Minnesota, Nebraska, Ohio), New England (New York and Massachusetts) and the Southeast (Alabama, Florida, Tennessee). Two-thirds of the graduate schools were also located in the west (Arizona, California, Colorado, Idaho, Montana, New

Mexico, and Utah). The Midwest was represented by Arkansas, Illinois, Iowa, Michigan, Minnesota, Missouri, Nebraska, and Texas, and the schools attended in the east were located in Florida, Maryland, and Virginia. Three scientists were educated at the University of Idaho (reflecting the proximity of the Idaho National Laboratory).

All but two (both male) of the scientists reported that they engaged in the typical high school extracurricular pursuits. Two-thirds participated in sports (football, basketball, baseball, volleyball, swimming, tennis, cross country, hockey, and lacrosse) and one-third participated in music (chorus, band or orchestra). Eight of the scientists were involved in both sports and music. In addition, seven scientists participated in student government, three in drama, and three in student publications (yearbook or newspaper) and four in language clubs (Spanish or French). Other clubs/activities mentioned were debate, service, Amnesty International, ski patrol, Future Business Leaders of America, chess, and art.

Scientists' Non-school Science-related Experiences

The family played a profound role in the scientists' attitude towards science as they were growing up (Byrne, 2000; Ramey-Gasset, 1997). This manifested itself in many ways, including the destinations of vacations and trips the family took, the kinds of toys that were given, the family discourse and discussions (e.g., around the dinner table), and the importance of books within the home. It should be noted that, even though this dissertation is supposed to be about high school science-related experiences, this next section is the result of obeying the same adage that guides the forensic scientist – follow the evidence wherever it leads.

Family Trips

Twelve of the scientists who addressed the follow-up question about whether or not they visited science-related places while growing up replied in the affirmative. (For the sake of this discussion, “parks” includes state and national parks and monuments, e.g., Yellowstone, and “museums” includes historical and science museums, science centers, planetariums, and arboreta.) Seven recalled family trips to both parks and museums, three cited only museums, and two cited only national parks.

Of particular note are two separate trips in which the budding young scientist had a close relative (an uncle and a father) with a special “inside” connection that seemed to turn what might have been an ordinary visit into an influential event:

> I had an uncle, who is now retired from Lockheed Martin, who was an electrical engineer. I can remember in high school getting a tour of the facility, a Lockheed lab, and they designed electrical components for helicopter cockpits. And that was pretty exciting. I remember getting to tour his lab and sit in a helicopter simulator and play with the components his group was designing and that was fun. So there were some experiences like that that got me fired up. (DC)
>
> Since my dad was a physics professor, they had a physics club at the university so for a couple of years they went on trips so our family went along with them to all the museums in Oregon. Stuff like that that isn’t typical but we were at that formative age where you could get to see the different applications. (DN)

Science “Toys”

All of the scientists who answered the question about having science “toys” growing up recalled having some kind of experience with them. Fourteen of them mentioned more than one. Fourteen scientists owned Chemistry sets (or played with chemicals), ten had access to a microscope in their home, four used erector sets, and seven were very interested in animals (e.g., tadpoles in jars, lizards and snakes) or had collections (e.g., insect collections). Other toys mentioned were building blocks, Legos, nature sets, electronic kits, and spy toys. Interestingly, all but one of the scientists who played with chemistry sets while an adolescent ended up in a chemistry or biochemistry related field.

The richest experiences – the ones that seemed to have the greatest influence – were always in close association with family or friends and did not necessarily involve commercial products but "toys of opportunity." For example, the advantages of growing up on a farm included gaining "hands-on" experience manipulating equipment, acquiring a deeper conceptual understanding of how things work, being exposed to all the natural biology of living plants and animals, and developing a greater sense of scientific process and experimentation. This exposure was profound and its impact continued long after high school, as the following two recollections demonstrate:

> I grew up on a farm… And on the farm you know how to make a piece of machinery work. Mechanically, electrically, you've got to plumb things, you've got to build things, you've got dirt, you've got plants, water, you've got everything that I still play with to this day. Those things I didn't understand then. I still can see pictures in my mind of things that I saw that, you know, sometimes I began to understand patterns and pictures. Mental images and facts going on – I didn't understand [then] how they fit together so there is stuff from decades ago that occasionally go click and you go "aah" that's satisfying. (MA)
>
> Well, I think you live a science experiment there [on the farm] because I was around life cycles and everything under the sun, and the seasons and things growing. I know a lot of people that I have worked with here grew up in rural environments, too, and we often talked about this and another thing is we have a lot of hands on experience with

> equipment. You had a lot of stuff that's very useful to experimentalists and I think those are things that we are missing now. And this is probably just a bias, but most of the toys you have now do everything. You had to find things to play with more so when we were young and you put things together, and now everything comes talking and you don't have to talk to the dolls… (JP)

Another "hands-on" profession similar to farming which appears to be conducive to future scientific inclination is auto mechanics. In many respects "tinkering" is analogous to experimenting. The benefit of sated curiosity and the confidence and satisfaction that comes from successfully getting an apparatus to work again are powerful motivators and foster future success:

> My father was an automotive mechanic [so] I spent a fair amount of time working and helping him out. [It] probably gave me a good background in how to build and basically tinker with stuff and make it work. So that was probably part of it – building and putting things together and seeing how it works. You get something and tear it apart and put it back together, so there was that part. (DK)

Whether tinkering with large, clunky farm machinery and cars or miniature electronic circuits and appliances, the significance of disassembling things and putting them back together so that they work cannot be underestimated. The following two accounts both show the progression of a hobby as it matures into an integral part of a career. The second rather lengthy quote also illustrates the essential influence that others (an uncle, grandfather, neighbor, and friend) have in its pursuit. It also reveals how early exposure and knowledge forms the foundation for future understanding and success:

When I first started in electronics I took things apart a lot and looked at them to see if I could see how they worked and in some cases in some rudimentary fashion would understand it. I took an electronic mixer apart – I remember getting shocked through that. So I think playing with electronics and [it's] a natural thing to start soldering things and building your own little tools. A couple of friends and I from some schematic diagram of a synthesizer (a simple oscillator box) – we built a little electronic device that could push buttons and change tones. (MP)

My uncle was a janitor at a high school back in Minnesota when I was real little – that would have been when I was six. He gave me a book for Christmas, a book on electronics and radio for children. It was fairly technical, but it explained how you could put a radio together – a crystal radio. Out of the clear blue [he] just gave me that book. And that was fascinating, and my grandfather helped me put together my first crystal radio set, helped me go get the parts… When I was eight I moved from Minnesota to California. And when I came to California I tried to find more things to do. I found there was a neighbor who worked at China Lake facility, one of those labs out in California, and he could get surplus parts and so I used to go with him and get surplus electronic parts and stuff. So actually I started out at quite an early age, and that's just been my hobby I guess. The radio developed into a ham radio, and I started to do that with another fellow who was big on ham radio…and again I realized I enjoyed the electronics, the making of the radio and how radios worked more than talking to people. I'm not that social. But I realized then it was really the electronics, really the physics and the science of all that stuff that I really enjoyed the most. So I was really studying that when I went into high school. And so when physics came along I guess I didn't make so much the connection with that but it

> all came together when I saw physics was describing the things I was trying to understand. So there was a big connection that way. That's probably when I realized I'd like to try physics [as a career]. (KT)

The chemistry set is another classic science toy and was cited by the scientists more than any other. The young chemist gains experience manipulating test tubes and burners, following instructions in the accompanying manual, designing novel experiments, and attaining at least a precursory understanding of important scientific principles. Again, this toy's impact was greatly augmented when supported by family members or friends, this time a father:

> I think I was seven or eight when I got my first chemistry set. And all through growing up probably until I got into high school I remember that since my dad was a chemist that I would go leave him a note in his briefcase, "Can you bring me some test tubes or some Erlenmeyer flasks?" or "I need these salts." or something like that and he would bring me home stuff for me to use in my experiment. Again, it's not really a hobby but something that I did on my own that I was interested in. My dad basically enabled me to do it. (FR)

Finally, it should be noted that the influence of the "toys" enjoyed by the scientists when they were young required not just the *access* to them (because of circumstances or financial resources) but the *freedom* to play with them, in an open and non-structured fashion that encouraged experimentation and creativity.

Reading

All but four scientists indicated that reading during adolescence was at least a small component of their adolescent upbringing. The personal reading materials ran the gamut from comic books to the *Hardy Boys* and *Nancy Drew* to old biology books and medical textbooks. Included were the following genres: science fiction (mentioned six times), adventure, history, fantasy, detective, and the classics. For several of the scientists, their mother and/or father read to them on a regular basis while they were growing up. On occasion, the reading took place primarily at the local library.

The following reflections show that reading can be a necessary escape into a safe world that nurtures a dream, an introduction to physics (or pseudo-physics), and a way to level the economic playing field – in an economic way:

> You know, they say I'm the kid who was bookish. Kids can be very mean to each other. And I remember those mean comments. And I said, "No, if I have to isolate myself to do this, I'm going to do something to prove that I'm just as good." Reading was my fantasy. In my fantasy world I was running four or five laboratories and people were running up, "Here's Dr. R_, here's the scientist that was researching." And I would go to the microphone and [announce] "I just found a cure for sickle cell!" I literally lived that fantasy in my mind. And I immersed myself in science fiction. Just devoured it. I lived in my mind a fantasy world. I became that person. And I don't think that we allow kids to fantasize enough because of reality TV. (WR)
>
> I was an avid science fiction fan from way back. I loved comic books, DC comic books in particular, which seemed more scientifically bent at the time than other types of comic books… They seemed to be more based in physical capabilities – the Green Lantern had a ring that gave him powers, some sorcerer's power. The guys on the Marvel side had big muscles and we used to have big debates – DC guys vs. the Marvel guys… The key thing of course was time travel. It was addressed a great deal. It's really impossible, but I'm sure there were a few references to Einstein in the comic books and how when

> Superman traveled fast enough, he would actually be doing himself some physics. It's all science fiction. It was fun to read. (TR)
>
> In fact, my mom, who was the elementary ed teacher, paid me to read books when I was in first grade – a nickel a book, ten cents if they were hard. So I read, and I do think reading is the educational system's right. If you can do nothing else for kids but teach them to read, then you've done your job, because I think they can educate themselves, if they're motivated enough to do it. In a rural school, I think we had a chance to exceed, to excel. (JP)

Issues

Nineteen of the scientists interviewed were captivated, to various extents, by at least one science-related issue during their childhoods. The passion for these issues grew out of rousing discussions at home, the more private pursuits of reading or watching television shows about science-related issues, proximity and access to science laboratories, and personal struggles with a disease or illness (or the affliction of a loved one).

The issues fell roughly into four categories. The first category, mentioned eight times, was space (e.g., race to the moon, space missions, living near Edwards Air Force Base; the second (nine times) was the environment (e.g., endangered species, invading species, clear cut logging, deforestation, water quality, ecology); the third (five times) was medicine (e.g., infectious diseases, neuroscience, living near an infectious disease lab in Montana, having cystic fibrosis or asthma as a child). The last issue, specifically mentioned once but often related to the others, was political, and is summarized by the following overview that succinctly describes the milieu in which many of the scientists grew up:

> I grew up when Kennedy said we were going to the moon, we had atomic bomb drills in school, my high school class had math books that were published to help us beat the Russians, technology was a golden boy – the hope of the future, and Mrs. [Lyndon] Johnson implored us to keep America beautiful. (TA)

When we think of "big" science, we often think of the pursuant structures and technologies, such as huge dams, lofty skyscrapers, mile-long bridges, cavernous aircraft carriers, and tunnels that burrow under entire bodies of water. However, few projects were (and are) more visionary and awe inspiring than the space program:

> But I think my generation, which are people who were born in the early fifties, were kids in the sixties – in fact I've talked about this with other scientists – I think what really probably got a lot of us interested in science was the space program. Today I think is the 35th anniversary of the walk on the moon and that was a seminal – the new frontier, the space program, get a man to the moon, you know. I remember standing in the backyard and looking at Sputnik and I think science was a lot more glamorous in the sixties because of the space program and I think that a lot of things were possible and that was an optimistic period of time in some ways, and I don't think we have in some sense the big programs that focused people, and things are not miracles to us anymore. There were so many things that really are sort of scientific miracles – we're sort of jaded and not so easily impressed now as when you are sitting there in your living room and watching someone stand on the moon… (JP)

If space elicited a sense of awe and excitement, concerns for the environment provoked particularly strong feelings of concern and urgency, as illustrated by the following remarks. The first is somewhat reactionary, and the second is a more measured and pragmatic response:

No, my parents were not into science in terms of the careers and what they did or anything. But I have to say that my mother probably has the biggest influence on me and it sounds kind of hokey but my mom was a very, for that time, liberal person, progressive, and she was very concerned about environmental issues. It was the seventies and there were a lot of different viewpoints that I remember and she was awfully concerned about environmental issues that weren't getting attention while we were doing space missions and things. And so, we heard about it a lot and she would tell us about various things on TV and documentaries and made us all sit down and watch them. My older sister also went into science and I really believe that that was my mom's influence. (MH)

Again, with the biology and the close relationship with that to ecology, my initial interest was to make a contribution in those areas, so that was what I wanted to study when I left high school. In the early 70's, there were lots of parts of the U.S. that were a mess. This was widely known when we were in high school that the environment was not very good. In order to do a better job, in order to take care of things, an advanced understanding of biological systems was needed. That was underlying what my motivation was going into science with a biology major… It was back in those days when we had the Chicago River catching on fire and it was the type of thing that was widely known to lots of different people. When you drove up to Chicago, what you could see was a brown cloud. The first time we came upon that, I thought it was raining there. It was just smog. So, certainly in my age when we were growing up, lots of people understood that environmentally there were lots of difficulties. (GG2)

Certainly, all four of these influences (trips, toys, reading, and issues) are forms of non-verbal encouragement, whether passive or active. Only three of the scientists received little or no encouragement at home to pursue a career, much less a scientific one. This was confirmed by the fact that, for these few, any experiences on trips or with toys that they had were enjoyed independently of the rest of the family. All of the other scientists received varying degrees of positive encouragement. The minimal encouragement was motivated by purely economic reasons, e.g., to get a decent job. For most of the scientists the parental encouragement was substantial – more than merely verbal. After all, planning a family vacation, selecting and purchasing toys, reading to your children, and discussing scientific or other issues with them is intentional and requires a commitment of time, energy, and resources.

Positive Parenting

The essential, if not *quintessential*, parental attributes that shaped and molded the scientists are remarkably similar to those of an excellent teacher, as will be demonstrated later in this chapter. The fact that they were manifested at the most formative and crucial times in the childhoods of the scientists must not be glossed over. The first and perhaps foremost attribute already mentioned by most of the scientists was that their parents *encouraged* them, especially by affirming them in their aspirations and by sacrificing so that they could achieve them. Two quotes, one about a mother and one about a father, corroborate this:

> Yes, my parents were very encouraging as I pursued my career in science. My mother used to stay up with my younger sister and me as we did homework (high school and college) and she would cater to our needs. She told us that she was proud of us, the way we took our studies so seriously and that since she did not understand the work all she could offer was her service, which included making us hot chocolate or bringing us food

> since we hardly moved from the spot we were studying. My younger sister is now a practicing Ob/Gyn. (EP2)

> My family was at the lower end of the ladder. My father worked two jobs – 60 hours per week. My mother worked in the junior high school cafeteria. Neither had health insurance or many other benefits… Neither of my parents was well educated. My father was not able to finish high school due to family needs at the time… My parents were always very supportive of anything I wanted to do, especially in academics. My Dad made a special room in the garage for me so I could pursue my electronics hobby in a safe and heated environment. They often gave me books on electronics and science. (KT)

A third quote summarizes this supportive atmosphere and its positive fruit:

> I hate to sound like a fairy tale, but I don't think I have any [disappointments, regrets]. I have had help all the way along, and that encouragement – my family encouraged me. And that is a huge part of it, if you have family backing you and saying you can do anything and to go for it. (MH)

A second attribute of positive parenting reflects the *wisdom and work ethic* acquired through years of responsible living. Encouraging parents not only set the bar high, but also stick with their children while they strive to reach it, as the next two quotes clearly depict:

> Maybe the one thing that I was glad of having what I did in High School was taking a lot of harder courses than maybe kids that I was running around with. They would say, "Why would you want to take such hard classes?" But, after talking to them once I had been in college for a while, they realized "Now I know why he took those courses." because they were having to do it all in colleges rather than then. So maybe the big influence then was my parents pushing me to do those harder classes, and that it might

> seem rough at that point but being able to have that experience and being prepared for it when I did get to college. (BL)

> She [mother] was interested that my brother and I were particularly good in math which I think is an enabling thing for science. She also saw it as a glamorous profession, like a neat thing to go into so I think I was encouraged by her. I certainly was not discouraged by her, and my parents definitely thought that I should go to college. They didn't care what I did ultimately but just more if you went to college because it is good to go to college. I grew up in an atmosphere that sort of fostered that. (JP)

Some forms of encouragement are not recognized as such at the time but only in retrospect. One of these forms is *discipline* as the next two reminiscences, one from a scientist who grew up with meager resources in the inner city, and the other from a scientist who enjoyed a more privileged upbringing out in the country, attest:

> She [mother] was fairly illiterate, went to tenth grade in a rural area, so that tenth grade education probably was a fifth or sixth grade education in an urban area, but she simply did not want her kids to have the same predicament – grow up in the same circumstances – that she grew up in. She just told us, "I don't understand what you are doing. I can't read this, but I want you to spend your time reading this. You can't go outside until you're through." She put these constraints on what we could do outside the home. We had to stay inside reading. She couldn't read the information, but she knew that whatever we were doing was important. She was a strict disciplinarian. (WR)

> I grew up in the middle of the desert so anything you wanted to do was, you know, you could blow up things and there's really no repercussions to doing it. My father, by the way, is literally a rocket scientist – he developed solid propellants for the Air Force

> missile systems. And so from an early age we used to ignite things and blow things up and my friends still talk about a classic case – we were making bombs using uncontrolled chlorine reactions and we added water to them to blow up bottles and then my dad – I blew something up right next to my ear, and my dad found out about it and lectured us for two hours about chemical reactions and chalkboard talk and everything. My friends still talk about "Remember the time your dad…" (FR)

The benefits of sound discipline are too often negated if the one meting out the guidelines and constraints does not practice consistently and faithfully what he/she preaches. In other words, encouragement in all its forms becomes both genuine and effective when coming from a positive role model. Two more scientists reflect on their mother and father, respectively, as these kinds of examples:

> She [mother] talked a lot about the environmental work that people were doing. A lot of that might have happened when… I was living at home, so it must have been an influence during high school. It was a consulting firm that did ground water hydrology and contaminate transport studies which is what I eventually, a long time after college, went into. (MP)

> He would bring reagents and things home and it'd be these different chemicals, and he'd bring them. For a while I was interested in model rocketry and I actually made my own rocket levers and my dad probably had something to do with that – I probably didn't recognize it at that point in time. I was mimicking him. (FR)

Much has been written about the fact that teachers at school act *in loco parentis* – in the place of the parent – and, sadly, all too often *as* the parent when there isn't one at home. However, sometimes the reverse is true, as the next two quotes portray, when the parent acts as a teacher in their more formal role of pedagogical instruction, even all the way down to a chalkboard, as was mentioned in an earlier quote:

> Well, I made the safe and sane ones [rockets] out of toilet paper rolls and food coloring… My dad's an engineer; I was being taught principles my whole life that I had no idea would be that handy. I mean, I was like eight, four, six – something, and I knew that you could turn up running water hot, really hot, and it would look like it boils more, more steam would come up, and it was a phase change – not in those words – but it was a true phase change. You could feel it, know what it meant, and know the temperature didn't go up because we did that experiment. Later, you know, later in physics, in college, I was astounded people didn't know that – just blew me away. There were all these fundamental concepts that I already knew, you know, just growing up with my dad that I was just blown away that people wouldn't know. (CR)
>
> My dad would make you think about – you'd ask him how to do something – he wouldn't just tell you, he'd make you [think]… He taught you how to use a calculator so you could calculate the cosine when we learned trig and stuff, and I was able to pick up, and I remember that I picked up on that stuff much more quickly than either my brother or sister did. (TW)

In concluding this section, the encouraging, role modeling, disciplining, and teaching become the platform for the dissemination of wisdom, and the structure within which knowledge and understanding flourish. As an example, the next retrospection culminates in some sage advice. A scientist who grew up in the housing projects without a father, but had a mother and grandmother who faithfully exhibited all four attributes, expresses the final thought:

And I remember thinking, you know running to my room and thinking, to put a gauge on a non-collapsible bottle – you know the glass bottle with the gauge on it? – and it would be my first invention that – at [age] twelve or something – and it would be an altimeter so you can tell what altitude you're at! And I remember being just crushed that it had already been thought of a long time ago. And then my dad gave me some really good advice that I still carry. You know he was human; he still gave bad advice, too, but this one: he said, "You know, if you invented something that's been thought of and that's the way things are, you are on the right track. You know, that's something to be extremely proud of, nothing to be bummed about." And you know it's pretty easy to see that's the truth. (CR)

I think, looking back, I think about the kids that I grew up with. Bright kids. And we were all about science and medicine, but once they hit a certain age (teenage years…age 12 or 13) the pressure to do other things came and it took them away from some of their dreams. These kids lost their dreams. The ones who succeeded were the ones who really harvested their dreams. And the ones who failed were the ones who didn't have enough around them to nurture that. And so I concluded that these kids needed a strong nurturing influence in their lives – someone to tell them "you can do this" constantly. If they don't get that after fourth grade or fifth grade, they turn off. So there's this period where you HAVE to have that. You have to be told you can do it. The great period in life in my youth was fourth grade. If they didn't have someone in their lives after fourth grade pushing them then they wouldn't do it. (WR)

Scientists' In-school Science-related Experiences

This portion of chapter four will investigate the same experiences delineated in the review of the literature (chapter 2) and in the same order. It should be noted that several important limitations became apparent as the interviews were conducted. Not surprisingly, the first was the inability of many of the scientists to remember the more detailed or technical aspects of their science education, such as their textbooks, special activities and labs, or the specifics of their teachers' pedagogical styles.

Second, because of the age of most of the scientists, and because of the time it takes to matriculate through college and graduate school and then establish themselves in a research setting is often at least ten years, even the youngest of scientists had little exposure to, or benefit from, the burgeoning technology that has burst onto the educational scene and become commonplace during the 1990's. Consequently, the influence of technology was usually merely speculative as the scientists considered how they would teach science if they had the opportunity today.

Influence of "Place/Time" (Informal) Programs

For some of the scientists their high school science experience was most unremarkable. In fact, one commented,

> I see High School myself as more of a holding pattern to keep kids engaged and out of trouble and I'm sure you'll teach them something, but I'm not sure how much they retain. I think there are very few kids at the high school level that can really excel at the ultimate program. (EM)

However, this assessment is certainly not shared by most of the scientists who were interviewed. As the interviews will show, there are many factors that can contribute to a positive and influential experience, and different factors will impact different students in different ways.

This section will provide an overview of those experiences that took place either within the formal setting of the classroom, or under the auspices of the school and its science department. In separate and later sections of this chapter the influence of the teachers themselves and the influence of their teaching styles (pedagogical practices) will be addressed, though obviously there is extensive overlap. It is extremely difficult to separate the influence of a teacher from the influence of their pedagogical style and practice.

In-school science-related experiences include science fairs, competitions (e.g., build a mouse trap or bridge), science projects, and science clubs. But they also encompass the myriad of labs, demonstrations, and activities that are an integral part of the curriculum. Following are three recollections – one each from physics, chemistry, and biology – that stand out for several reasons. The first is their detail after so many years: The activity and the lesson it taught must have been indelibly imprinted on the students' minds. The second is the fact that they each involved the student doing something: The student was not merely a passive observer. The third is the sense of accomplishment or ownership engendered by the activity. Finally, they each contributed to the student's understanding of the nature of science as much as they contributed to the student's factual base.

> And you put an eyebolt in the ceiling and you had a bowling ball at the end of the chain that would reach down from the ceiling. And he would take a victim and stand him up against the wall so that the back of his head was against an immovable object. And then he'd hold the bowling ball at your forehead and he'd let it go, and he'd watch it swing all the way across the room and come all the way back. Not very many people could stand there as it came back. That's the sort of thing that he did to really imprint on us these

> visceral feelings of physics. I'm sure nobody in that class ever forgot the fact that the pendulum doesn't swing back as far the second time as it did. (TA)
>
> My most memorable experience in chemistry was when we had to grow crystals using salt or sugar. When I went home I tried it and didn't feel challenged. So, I found some cupric sulfate from a chemistry set my mom had (she was a biology teacher at one of the community colleges) and thought, "This might make some really nice blue crystals." So, I tried it and it worked. They were huge, translucent crystals that made the salt and sugar crystals look elementary. Needless to say, I took the cupric sulfate crystals to school and I was the only one in all her classes that made a perfect score on that project. All the other students thought that I bought the crystals at the store. (RB)
>
> And if I can point to one thing in high school coursework that really directed me, it was this project that he assigned where we were to go home and identify some place: could be your backyard, could be your front yard, could be a local park where first you would map this area, and then…on a daily basis you would go and make observations. And you write it all down, and that was part of the report. And I think that in some ways that was really one of the most…that was really a neat experience! And this one portion right below my parents' house was sort of a lot but it was filled in with trees and everything and there was a little spring there… You'd have to walk it to really make observations. And this made a big difference in my expectations of science. Actually, I think it got me really into descriptive type science or discovery type science, and I differentiate that from hypothesis testing, and I really think that it motivated me. (RC)

Special speakers can also influence future scientists. Not only do they bring a fresh voice and perspective into the classroom, but they also bring real-world experience in their field and the credibility that goes with it. Finally, they cause an ethereal reality (having a career or job someday way off in the future) to become a very near reality for the student, at least for the hour that they are speaking. Nonetheless, very few of the scientists mentioned guest speakers, with the following exception:

> So, the last year I took a physics class. Actually, that was at the time of the satellite, Sputnik and all that stuff…we had a few people come over from a company called TRW. They did aerospace and gave a lot of neat seminars on what was going on in science. I was studying physics at the time, though I didn't really make the connection that well… I guess I was influenced mostly by those seminars. (KT)

Few of the high schools had science clubs and even fewer of the scientists participated in them. Like so many organizations, each club's success depended on the vision and commitment of its leadership. But, considering all of the competition from sports and music for a favorable time slot in which to meet, and students who are often heavily involved in other activities, it is no wonder that the clubs received mixed reviews. Two of the scientists who were part of their school's club (one was the president) did not comment about it, and the second of the two scientists who reflects below on his club was not a member:

> They actually had a physics club and then they started this gifted program, which they called "$E=mc^2$" type of thing and so then there were quite a few of the kind of science geeks in that type of club. And what they tried to do was to get you an opportunity to go out in the community to someone who did something either science or engineering-based. It was difficult because Kingman is sort of a blue-collar town so there's not that many people doing that kind of stuff. And I actually went to a law office because I thought I wanted to be a lawyer (ha, ha, ha) but they did attempt it. And I know in the physics club

> they did actually work… on coding things and writing sort of interface stuff with some type of equipment and stuff. (JI)

> The science club at my high school did not have a very positive reputation among most students. *Why wasn't the reputation that positive?* That's a hard thing to answer. I think it just depends on the high school: who's leading it, how many kids are involved. It tends to be small, which the one at our high school was. Not many people were interested in it. It was after school; it had to compete with a lot of other activities. If you are involved in other things, like sports or music, those tended to take precedence. The science club, I know in my case, I was more interested in doing other things than joining a science club so I really didn't get involved in it at all. I was involved a lot in music and sports and that took quite a bit of time. *Was the reputation one of "the kids were a bunch of nerds" or what exactly was the reputation?* Basically that was it. They were a bit strange or different and didn't attract a lot of people to the club just by knowing who was in it. (DT)

Nine of the scientists recalled doing science fair projects, though often it was during elementary school. The benefits of participating in a science fair are similar to those already listed at the beginning of this section for classroom activities, i.e., they are hands-on, give a sense of accomplishment and success, and teach the nature of science. Parenthetically, the second of the next three narratives alludes to what can be both a strength and a criticism of science fair projects – the extensive involvement of parents. A student without adult encouragement and assistance is at an inherent disadvantage, and a student with too much parental involvement doesn't really learn anything:

> Another experience I remember from high school chemistry was my science project. I wanted to show how NaCl was a conductor of electricity because of its positive and

> negative charges. So, I bought one of those big batteries (with the two posts – can't remember what size they're called) and a flashlight light bulb. At first, it took me a little while to set it all up but I finally connected the positive post to the battery directly to the positive side coming off the light bulb holder; and with the negative post I ran a wire into one side of a container containing approximately one molar NaCl solution and another wire on the other side of the container ran to the negative side of the light bulb holder. It worked! The light bulb came on. Unfortunately, I kept playing with it and by the time I got to present it for the science fair the battery went dead. However, I had satisfaction in knowing I made it work even though no one got to see it in action. (RB)

> I actually won the science fair, the grand prize of our fair, which went all the way through junior high, and I embalmed a pig heart. I went to the funeral home and bought embalming fluid, got a pig heart from a slaughter house, embalmed it and labeled all the parts on it, which I thought was pretty creative. And I always won ribbons there, and again, my mom was pretty encouraging in helping me set up experiments and stuff. She was the one that was probably the early influence that launched me into the science fair, and she'd pick out an experiment and we'd do it. (JP)

> I think I was in every science fair since I was old enough to participate. I can remember the first one when I did rose petals. I mean, it has stuck in my head since elementary school. I have always, to this day, organized them at my son's school. I am a judge at the expo. I am a big proponent of science fair. (MH)

Influence of Previous Courses and Success

A popular aphorism in the business world avers, "Nothing breeds success like success." This is often true in science education, as the research about challenging courses and adequate math preparation has shown. The encouragement that success engenders shows up in other ways as well. In the first memory following this paragraph, a vocabulary term that was, to that moment, an arcane factoid became a stimulus to further scientific pursuit. Somewhere along the line someone or something exposed the scientist to some information that might have seemed, at the time, beyond his years. The second memory suggests that an excellent education entails continuity in *time* – good instruction over many years – and continuity of *place* – good instruction both at home and at school. (This principle of continuity is glimpsed frequently as it gradually emerges throughout this chapter.)

> Junior high is where I got interested. I was a very nerdy, science-oriented kind of twelve-year-old in seventh grade and I remember – the memory stands out in my mind – I "thought" I was very cool when the teacher asked if anybody knew… what DNA stood for, and I raised my hand and said deoxyribonucleic acid. Well, that was the end of my reputation after that, but I was excited about science. (DC)
>
> I think also being able to perform well in the classroom and to do the exercises kind of feeds itself – if you're doing well then it's not something that you view as an impossibility to take it into a career. (FR)

Sometimes it is not so much prior success that propels the nascent scientist on to the next level, but carefully crafted experiences that maintain the interest and attention long enough for success to become imminent:

> Actually, when I think about my interest in science, it probably goes to the sixth grade when my sixth grade teacher gave us a project where we were to collect mushrooms and learn about mushrooms. And I though it was so great! I just loved it! So by the time I had gotten to high school, I had sort of a science tendency and I enjoyed those sorts of

> things. And I had broadened my interest beyond just fungi to plants. Through high school and into college, plants were my thing. (RC)

> I guess my science interest came before junior high… I remember now in fifth grade having a science class and it was my first true science class where… We left our homeroom and went to a separate room and had a science teacher teaching a science class. That was fun. So fifth and sixth grade, we had projects, there was a science fair, maybe even in seventh and eighth grade. I can remember doing things like, you know, building a papier-mâché volcano like everybody did and that was fun stuff, making little electrical circuits in junior high where if we did the little electrical circuitry right the little light would light up and we got tested at each step of the circuit based on whether the light was lighting up and if we had a problem we'd go back and troubleshoot and find where we had a short or something like that. I did much more hands on, interesting stuff like that in fifth, sixth, seventh, eighth grade. (DC)

This section closes with an example that proves how powerfully significant prior success can be in ensuring future progress. When continuity of place and time does not exist, and in spite of dire circumstances, a specially designed program (in this case, during the summer at a private preparatory high school in New England) and the benefaction of caring people (in this case, supporters of a scholarship for inner-city students with a proclivity for science and math) makes all the difference:

> I had computer 101 with white kids, and I realized I was making the same scores. I was in the same city, so I said, "Well, I'm just as good as they are!" And that was important going into Yale. So I walked in there and I didn't feel intimidated. (WR)

Influence of Science Textbooks

None of the scientists claimed that their textbooks were instrumental in their science career persistence. In fact, most scientists could not even remember their textbooks at all, much less anything specific about them. But before they are dismissed outright as so much excess baggage, it must be noted that for many scientists their textbooks were essential tools for success, but for a number of very different reasons. For example, in the hands of a conscientious student, the textbook is an invaluable resource:

> I was a very diligent student and used my textbooks, science or other, to the fullest extent. I read up on the information we covered in class and also did sample questions whether they were assigned for home work or not. I believe I got the best quality out of my books. I remember, particularly on Fridays, having my backpack full of books going home for the weekend for study. (EP2)

Other students, particularly those who had a more developed self-metacognition, recognized that even if others did not need their textbooks, they did. In other words, students have different learning styles and what is superfluous to some may be crucial to others, as the next two accounts relate. “As a book learner, I did well with the lecture style and was able to learn and understand by reading the text and oral explanations without an unusual need for ‘hands-on’ experiences” (HH).

> I always used textbooks extensively for any course I took. I did not generally use them ahead of time (prior to lectures), but rather used them to clarify concepts or to make sure I know all the required material for tests. *How would you have done in a classroom where there wasn’t a textbook?* I would have done very poorly. But it depends, I think, on what kind of learner the student is. Every student is a little bit different. I tended to

> be one who needs a textbook: I go back and look at it, try to put in perspective what I heard, and try to keep an idea of where we are in the class. Plus I go back and read about what I heard in a lecture. I may not always get everything straight or clear from a lecture whereas if I have a text I know at least that's correct and I can try to go back and understand it. For me, you know I use textbooks a lot, and I would have trouble if there was just a lecture course. (DT)

The textbook becomes the primary source of learning when the teacher is either frequently missing from the classroom – or the student is – for whatever reason, as in the next quote, or the teacher is ineffective because of poor teaching skills or lack of knowledge, as in the subsequent quote:

> I remember in chemistry – again because our teacher was gone quite a bit – that I ended up learning a lot from the textbook. And you know, to be honest with you, I can't remember if it was good, bad, or indifferent. But, to take the exams and stuff, I ended up having to spend a lot more time reading the textbook. In the biology class,I remember he used the textbooks with what he was teaching and it was sort of a nice balance. And I don't remember if the textbook was good or bad, but I remember he used it in a pretty nice balance… Definitely in chemistry I had to spend more time looking at the material because she just was [frequently absent]. (JI)

> I think my science textbooks were decent, and we used them quite regularly, with assigned readings. I also used them for references… but in chemistry I don't think I needed my teacher at all – he didn't really teach us anything, I just read the book. My physics teacher was nice and he tried, but again I probably learned as much from the book as I did from him. (YF)

Two scientists reflected at length about the kind of textbooks they would look for and how they would use them. The first felt that a good textbook is a valuable reference, resource, and a time saver. The second observed that modern textbooks should incorporate the kind of graphics afforded by modern technology, and should be as literarily excellent as the books we require students to read for a literature class:

> My experience was that if the homework problems came from the textbook then the textbook was a reasonable reference to be able to do the homework problems. I found it a lot more frustrating as a student to have problems generated by the teacher. In experiences that I can remember I felt like I didn't have resources to do the problem. So for my style in terms of what I would want to accomplish in having the students do the homework… I would want them to have a good resource readily available so they can figure out how to do these problems. I don't want them to have to spend a lot of time looking up somewhere else the material that they need to solve the problem. I'd rather have them solve the problem because in doing that they're doing the process and seeing how it all fits together instead of looking up information. (TA)
>
> It would have great graphics. I believe people can really remember graphics – graphics that hold big concepts. And [they must be] well written. You know yourself…you can pick up some and they read beautifully and they're really a joy to read whereas those others…you're never going to get through this. Beautifully written, graphics are wonderful, the pages just make you want to read, but the authors write beautifully and they bring in just a little bit of life in everything. (JB)

Finally, as one scientist remarked, "My daughter thinks that she can't look something up in a book: it has to be on the Internet. I try to tell her that chemistry really hasn't changed that much!" (AW). Maybe chemistry hasn't changed that much but technology definitely has. It is interesting to speculate on what will happen when the entire textbook is on a DVD or some other medium and made available to students. Perhaps students will use them more if they don't have to lug them around in their backpacks but just pop it into their laptops. (Further discussion about the influence of technology follows the next section.)

Influence of Extra- and Co-curricular Experiences

Just as there are today, a multitude of opportunities for exploring science and gaining scientific understanding outside the confines of the classroom were available to aspiring scientists. In most cases, these experiences were exceptionally influential. In all cases, some organization had to foot the bill, and some individual or group had to connect (via time, money, and/or transportation) the aspiring young person to the program. In this first illustration, the opportunity was readily available on television, and the motivating force was a parent:

> And there were a couple things that really rocked my boat back then and this is really silly but all those Jane Goodall movies. I cannot tell you how much I would watch those and think, "My God, it could be fascinating. What a life!" You know, look at the things that woman is doing. So that influenced me. And PBS [public television] – they also had these Saturday morning things that you basically could write in and become a lone member. It was like a junior science thing. And they did courses in the morning, on Saturday mornings, and we got kits and papers and stuff in the mail to participate. I actually learned in high school through PBS how to do an environmental impact statement if you can believe it or not. They had a whole course on that… So, that clearly influenced me a lot, and again I would say that was my mom's pushing that direction and my realizing that it could be fun and interesting. (MH)

Several scientists recognized the role that the Boy Scouts and the Girl Scouts played in the development of an interest in. Each organization provided avenues that lead directly to enrichment opportunities. A biologist, for example, recalled, “There was something parallel to the Boy Scouts called Explorers. I was in a forestry Explorers group, and we did work with the arboretum in Portland, so this is outside of high school” (RC).

Another example illustrates the broader impact of an internship regardless of the sponsor. Such experiences yield more than scientific knowledge or exposure to laboratory techniques. They instill wonder, build confidence, and expand horizons. There is much to be gained from being immersed in the culture of science, as this experience relates:

> And the other huge influence on me was Girl Scouts. I did girl scouts all the way through high school. (Rarely do you see the girls stick it out to their senior year. A lot of kids drop out of it.) And I had the opportunity and I think it was probably my ninth grade year, but Girl Scouts, it was a little known fact, but they sponsor all kinds of internships, and I applied for one and was accepted. They paid for the whole thing and sent me to Bryn Mawr [Pennsylvania] Campus. I think it was two or three weeks… And I stayed with a host family for a couple of days and went to campus for two weeks, sort of a crash summer course, on environmental studies. And Jacques Cousteau made an appearance but actually his brother taught one of our classes – and if that ever has an impact on a kid! You know, you’re watching these documentaries, you’re seeing this stuff, and then they come and teach a class to you, the whole college setting, everything was just right to really say, “Wow! This is something that I want to do.” So that seriously influenced me. So I got more of my exciting interaction and experience outside of high school in these other things. (MH)

The same benefits that accompany an internship are also realized in special courses and programs offered by local schools and universities, organizations, and civic groups. The first experience involves teaching and mentoring, and the others entail hands-on experience, authentic research, and scientific collaboration:

> And I also participated in something called outdoor school. When I was in high school I was one of the counselors for a class of fifth graders, and that's how it worked in our school or in our public schools. When kids are in the fifth grade they go with their teacher for a week to a camp just outside of Portland, and they spend a week learning about the outdoors. I was a counselor so I would stay with ten of these kids in a cabin, but during the day I was teaching them something, like nature hikes and that sort of thing… It was an academic experience, and for me, my grades had to be good enough that I'd be away for a week. I did it a week in the fall in my senior year, and then two weeks in the spring of my senior year. I missed a lot of school, but I was ok with grades enough that I could do it, and this is where my real interest in the outdoors was. In botany primarily…edible plants and what these particular trees are. I guess as an aside to what you're asking, it seems to me that most of my really inspirational science work was done outside of the classroom. (RC)
>
> There was a field ecology class and we'd go out and work over a pond and spend a lot of time separating bugs, or the birdology [*sic*] class I took in the summer time, which was the optimal time to take it, because the guy sort of lectured while we drove in a van. So every day for four weeks we went to different wildlife refuges and checked out different birds and looked at some other species as we could and then we discussed the birds. That

> was a much better experience than learning form the book. I mean you still had to read the book and take the tests. (BB)

> And then I was also a member of a society called SOAR - Society for Original Avian Research. We would catalog and band raptors. So there were field trips in Eastern Oregon or Central Oregon. I think it was an independent group that worked somewhat with the Fish and Game Department or the Oregon Department of Wildlife or something like that… I found out about it and had friends who were doing it. We just really enjoyed being outdoors, and observing birds was a passion for some… my brother was really into ornithology. So I absorbed some of that through him. (RC)

Of particular importance is the kind of program referred to in the next illustration in which the experiences would not have been possible were it not for the significant interventions of others. In this instance, the goal was not just enrichment, but ensuring the survival of a dream of pursuing a career in science. The program, supported by a non-profit organization and funded by concerned citizens, enabled gifted but disadvantaged students to travel to a prestigious preparatory school (Phillips Exeter) in Massachusetts during the summer and take computer and physics classes. (The real fruit of this experience is cited elsewhere.)

> The encouragement was phenomenal from everybody in my neighborhood, people in the church. I was very active in the church and they knew I loved science. And when I was in the ninth grade I really felt the need to escape from Memphis. And that is when I actually was taking a couple of tests and was introduced to a couple in Memphis, a Jewish couple, who really just embraced me and they wanted to see me go on. And they actually provided me with some of the financial resources and they financed the trip to

> Exeter and money for books. And they talked to me about escaping and really living my dream. Lots of people stepped up. (WR)

Sometimes the value of an internship or experience is that it directs you elsewhere, creates momentum, restores an earlier focus, or narrows the options. Such were the situations for the next four scientists, respectively:

> When I was in high school, I thought all I wanted to do was practice medicine. I saw that aspiring to be a physician gained you a lot of respect. It wasn't until later after doing some volunteer work at the hospital that I discovered that being a physician wasn't all it was cracked up to be. (RB)
>
> Actually it was these extracurricular things in high school that directed me in college and I think by the time, this isn't very realistic, but it may be appropriate for the early-mid seventies, but through high school what I developed was the idea that I wanted to be a professional naturalist, and there were a few of those people around. It's not what you call a very practical lifestyle that what you're looking for is a decent thing like that, but it's more something you pursue just because you love it. And I thought of that almost the whole way through college, and I gathered science classes so that I could sort of fortify that, in a sense. (RC)
>
> My summer experiences were attending a local university studying general courses such as English or Writing. Not too long after finishing high school I was accepted into a summer program at a private university/medical school and did a gross anatomy class along with other scientific/medical classes. I really enjoyed this experience and it was a reminder of my love for science. (EP2)

> I did an internship my junior year of undergrad at Montana State and I really liked microbiology. And with that then I switched my career in chemistry to microbiology in graduate school. (DN)

Finally, sometimes the experience that propels one into science is not an official, organized program but good old real-world experience:

> Not being in school had a big role. Seeing what I didn't want to do with my life was equally important as seeing what I did want to do with my life. You can't discount the experience that you have outside of the classroom shaping your future. The work I did in the oil refinery convinced me that I needed more education. Once I left that and went back to school and had some interaction with some science people, it helped direct that. (TR)

Influence of Technology

Not surprisingly, most scientists could not recall much technology (as it would be defined today) well enough to comment on its influence. Certainly, memory of such details from two or three decades ago was a factor, but the more obvious reason is that there was little technology to speak of when the vast majority of these scientists attended high school. A current definition of technology would not even include such things as filmstrip projectors, overhead projectors, and movie projectors which were familiar to them.

Like textbooks, technology can be used as a valuable tool to *supplement* the learning process, an infinite resource to *enrich* the learning process, or a *distraction* that substitutes for the learning process (i.e., it merely entertains). Two scientists, with young children of their own who now use the latest technology, share these insights in the following observations that are skeptical, prescient, and hopeful at the same time:

I think it's probably just like with the demos if it's used and it helps the student learn. But if you're just using PowerPoint, they [often] can't keep up with taking notes or something because you're going too fast. Or the other thing that I find now that I'm still learning is that if you have the PowerPoint presentation and your teacher just gives you the notes, while you're sitting in lecture you're daydreaming. I mean, if you're forced to actually write words down and keep track and make notes and stuff, I think that there's a good combination of those… I know in talking to a few of the professors they said that the Power Point sites… could give them very good diagrams, very good pictures, and they wouldn't need to necessarily spend a lot of the lecture time trying to draw these things if it's already there. But at the same time you want them physically participating… Another thing is even the same thing with using the Internet or using movies, tapes, CDs and stuff. I think it can just be to the point where the students really are just being entertained, they're not really having to physically do a whole lot of stuff. (JI)

My opinion of the filmstrips and things we saw wasn't very positive. Mostly it was a time-filler. And they weren't visually exciting. Technology has improved so much nowadays that it might be much more impressive and keep my interest. Back then I don't think anybody really enjoyed the filmstrips except that it was a day off from the lecture of the teacher… Just because it's fancy and impressive doesn't mean that it teaches something better or is of more value but I think it would be more interesting for the students to watch. And they could illustrate things much better than they could in the past. I've seen with work-related things… [that] you may be trying to get information on a certain process and you'll look up, for example, "mitochondrial function" and someone will have this wonderful diagram and animated video that you watch that very clearly

> shows what is going on. And in that sense it helps a student to understand it a lot better than sitting and trying to draw the thing on a chalkboard. So certainly the technology can help – whether or not it is a better teaching tool [than more traditional aides] is always a question. (DT)

The final observation was made in response to a query about the value and use the scientist himself would impart to technology if he were a science teacher. Two benefits were anticipated. The first is the savings in time, something that is true in any application. The second is the efficient way in which technology can model that part of the universe that is being investigated:

> There are two things. One, they save an incredible amount of time and they enable you to see things more quickly, just because of the power that they give you to manipulate your data and display it. So I think it needs to be integrated into the laboratory. The other real value I see is that for most things there's a model that goes along with whatever the experiment is that you're connecting and there are a lot of those models available. So if you could integrate the model with the experiment it goes a long way to helping someone understand what the significant parameters are in the experiment and gives you a way to explore the experiment quickly and cheaply to get a feeling for how things might behave before you actually go out and do all the work of putting together your experiment and measuring things. So I think that it would be really good if you could integrate those two so that students have a model, a simulation that they could manipulate and then conduct the experiment to see if the simulation was valid or not. (TA)

A few comments about laboratory facilities are pertinent here. Even though lab benches and tables and the rooms they are in are not technology, in the future the technology will be seamlessly integrated into the design of the room and the very laboratory accoutrements themselves. Students are already using laptops to acquire data from dozens of electronic probes and analyzing their data in real time. Thus it will become increasingly difficult to separate the physical structure of the lab from the technology integrated into it.

Having said this, the scientists were nonetheless queried about their laboratory classrooms in their high schools. (For them, of course, the physical layout of the room and the available equipment were quite distinct from whatever constituted technology when they were in high school.) None of the scientists indicated that the quality of the facilities – or their deficiency – were particularly an overriding influence. In the following descriptions, the first scientist enjoyed a brand new, state-of-the-art school constructed in a suburb of Denver. The second scientist's school was an old, poorly maintained inner-city school:

> I was in a very new high school, and I think we had kind of the best of everything that was available at the time… So I signed up for biology, and I was at a very large university, and I think that if I hadn't had that real love and those very caring and dynamic teachers in high school, I would have forgotten that [science] and gone on to something else. In those early [science] classes you didn't get the attention or the excitement that you had in high school. And thankfully I was able to get through that. (AW)

> My high school was a big urban high school without a lot of financial resources. The laboratories themselves were basic rudimentary labs without a lot of money or equipment. We didn't have a lot of technology. The experience was really based on the teachers who were just passionate about science. They had so few students coming through who were interested in science that they grabbed the ones who were interested

> and nurtured them so incredibly well, giving them a lot of information, readings outside of the classroom, and looking at a lot of experimental data because we didn't have the resources to do this in classroom. I would say that [in spite] of the low technology labs and poor resources in the school, [it was] just the dedicated, gifted teachers that made the lab experience wholesome. (WR)

Obviously, when the resources are present, a good teacher will be a good steward of them, enhancing the science experience of the student. A poor teacher's impact might conceivably be partially offset if the student has access to the lab and the equipment. When the resources are absent, the experience of the student is much more dependent upon the teacher. In both of these accounts, it was the teachers that made the difference. This naturally segues into the next section.

Influence of Teachers

Within the science classroom, the interrelationships between the students, the curriculum, the physical environment, and the teacher are profoundly complex and do not lend themselves easily to even the most complicated of models. However, for the sake of structure, much of the rest of this chapter will be organized around a simple model of a pyramid, with the student, the curriculum, the environment, and the teacher at its corners. Each affects the others – its all about *relationships*.

The environment – insofar as it incorporates the lab area, technology, materials, and textbooks – has already been addressed to a limited extent. As technology, in particular, improves and is integrated into the very warp and woof of the entire education process, it will become ubiquitous and an increasingly indispensable tool. However, the environment's interaction with the other three components will not be investigated any further because the emphasis will be upon *personal* relationships. As one scientist observed:

> My sense is that we're looking for the influence of teachers and teaching on students' aspirations in the sciences and I think that's exactly right: it's the teacher [who] makes all the difference, exclusive of genetic or familial biases like mine that might predispose you to be considering science as a career opening. It's the teachers that can motivate about science. (FR)

The local community through a school board and the school's administration broadly determines the curriculum, usually with input from national and state governments and local organizations. The students affect the curriculum at a fundamental level because of their unique backgrounds, interests and experiences, and needs. The curriculum, in turn, ideally changes the students as they discover the information, embrace it, and integrate it into their thinking and lives.

However, most students do not themselves appropriate the curriculum directly – they need guidance. This leaves two sides of the pyramid yet to be explored: (1) the relationship between the teacher and the curriculum, and (2) the relationship between the teacher and the student. The first includes the pedagogical style of the teacher (how she/he chooses to cover the curriculum) which will be covered in a separate section later is this chapter. It also includes those attributes and characteristics, i.e., the *passion*, that the teacher has for the material.

The second relationship is greatly affected by the personality and relational teaching style of the teacher (not exactly the same thing as the pedagogical style) and the personality and learning style of the student. It is, perhaps, best summarized by the *compassion* that the teacher has for the student, but includes the teacher's approach to classroom management and student discipline. The interviews are replete with references and stories about teachers and their passion and compassion, though it is sometimes difficult to differentiate between the two – much like trying to discern between two precious metals in an amalgam. This section is divided accordingly.

Passion for teaching and science.

All of the scientists had strong feelings about what constitutes effective teaching. Sometimes the description seemed to flow from the memory of a particular teacher, and sometimes the memory of a particular teacher was conjured up after thinking about the characteristics of good teachers. Regardless, the rich portrayals and robust depictions seemed to fall into four categories: *contagious, content, challenge, and character*. Naturally, these descriptors are not mutually exclusive, and the quotes used to support each term will also allude to the others. (See Appendix M for a list of synonyms and a table charting the scientists and the particular teacher-characteristics that they emphasized.)

Passion for teaching and science: contagious.

Over and over again, scientists recalled their favorite and most influential teachers as being enthusiastic, dynamic, excited, energetic, inspirational, and passionate about their discipline. These teachers loved to teach and loved what they were teaching, and it was infectious. For example:

> But I think really just their passion made the difference and that carried through to college too and I know you're really focusing on high school but even undergraduate [school] was the same thing. If your professor is up there and just loves it, it's hard for you to go, 'I don't want to study that." So I think that that is really important. And I think that that is universal. (DN)

Not only can a teacher's love for a subject motivate the student to study that particular subject, but the teacher's enthusiasm can instill a love for learning, even if it is just to please the teacher:

> But the physics and the chemistry were really fun and I think that the things that made that interesting really were components of the teacher. Mr. S_ was our physics teacher and he loved it. He was the classic physics nerd – don't quote me on that [sorry!]. He just was this little guy that loved physics. It was hard to not like it… He just really liked it. It was very evident that he liked it. His enthusiasm made a difference and he was just one of those people you like and wanted to work hard for him. I can't put my finger on exactly what it was. But I would be excited if I saw him today. (DN)

In the following two quotes, one scientist was moved to change her course of study from an entirely different discipline to science, while the other scientist found direction as to which branch of science she would eventually pursue:

> I do remember that we had Mr. L_ for chemistry. I really like the way he taught the class. At that time I had no intention of going into science, I was certain I would be into business and law, something like that. *What did you like about his teaching?* Well, he was rather interactive; there were a lot of experiments and a lot of demonstrations. It also included class participation. I don't know, he was pretty laid back. (JS)

> Chemistry was taught by an elderly man whose name was Mr. S_. He was very enthusiastic about the subject. Every class was exciting and I could not wait to learn. Although my love for the sciences was sparked in the second grade, it was Mr. S_ who unknowingly helped me to narrow in on the specific science I wanted to study in college and that was chemistry. I enjoyed trying to solve the unknown. I find it to be a really

> good mental exercise… I believe even if I did not have the exposure to science as I did in my primary education, the experience I had with Mr. S_ would still be enough to enlighten me to pursue a career in the sciences… It was the sincere love for chemistry that I saw in Mr. S_ that had me second-guessing which path I would take when I got to college… it was all because of the brief exposure I had in high school. (EP1)

Sometimes a teacher's love and enthusiasm for the subject is not just an overt emotion but something that is backed up by hard work and going the "extra mile" in order to ensure that the students have a meaningful and enriching experience. For example:

> Another teacher I had, Mr. H_, I had him for physics. And again, he was sort of a youngish guy, but very active; he wasn't just standing up in front of us. But, when we studied astronomy, he organized a field trip out in the middle of the night to go see the stars, and it still sticks with you today… You can tell that they enjoyed it a lot, but they [good teachers] wanted you to pick up on how interesting and how excited they were about that. I think that's a big contrast to what I found in graduate school, where the people who were teaching, a few of them were really excited about what they were teaching, and some of them really were not. They could make a fabulous topic deadly dull. (AW)

The fact that some of the scientists reminisced about their college professors is understandable, considering how long it has been since they were in high school. However, those characteristics that embody excellent teachers do not change, as the following story illustrates:

> And I think that the enthusiasm is really key. If you don't like what you are teaching, if you are teaching just to be teaching at a job, you are not going to get your information off

> to the kids. You're just not. It doesn't matter if you're accurate. I mean, you have to be accurate, but if you are accurate and not into it, you are still not going to get your message across. My favorite teacher was in college. She was actually my advisor, Dr. C_, and she was a p-chem professor, a little, tiny, British woman. She was hysterical. She loved physical chemistry, loved it. She'd come in and say, "How are you?" "Fine, how about you," and she'd go, "I'm kind of tired," "Well why?" "I was just so excited about this lecture on thermodynamics that I'm going to be giving today." She'd do things like "What do I have to do, stand on the table and teach with a grass skirt on to get your attention?" And we thought that was funny until the day she came in and did it. You've got to be a little out there to capture the kids and really get the point across. It's hard. I think that it would be really hard. I think that the more years you would be in teaching, I think that you would kind of slump out of that because it takes more energy and more effort. (DN)

Incidentally, this last observation in the account above is a valuable precaution but not a guarantee as a teacher gets older. Recall Mr. S_ in the quote by EP1 earlier.

Passion for teaching and science: content.

Content is more than just the "stuff" of the curriculum – the facts, concepts, and ideas – that are supposed to be mastered. For the scientists who were interviewed, it was also the way in which the teachers communicated the content and enabled them as students to see it in context and appropriate it as their own. One way to accomplish this is to make the material relevant and engaging, as the following scientist explains:

> She was excellent because she would show you the importance of chemistry when you were in the biology class. She could relate, "Well, we went over this reaction and here's

> a real life example of it." So it gave meaning. And I know that students struggle with "where and when will I use this?" Well, we were given everyday examples of how we could use it. She was also hands-on. Some teachers don't deal well with an open classroom and they're more comfortable if it's lecture notes and text. Sister C_ was hands- on, lots of questions, and very demanding but it was fun. The kids enjoyed the class… I think it was that interactive teaching style that was really what made me fall in love with science. She's the person I would say that makes a difference. (JB)

To be "fun" should not be a goal in and of itself, but a means to an end. In fact, as the following scientist (a chemist) relates about his chemistry teacher, the emphasis on fun to the exclusion of comprehension would be a disservice, both in the short-term because of minimal knowledge of chemistry, but also in the long-term because of an imminent rude awakening in college.

> She wasn't really a fun type but she explained things very clearly. That was, as far as a science course anyway, my first introduction to what maybe college was going to be like because it was mostly lectures. She had a lot of class participation and she did do some examples in class whenever we did experiments. So that was a nice experience – my favorite science. (RB)

The next two quotes illustrate in a subtle way why a textbook or video can never replace the teacher – even when content is the only thing being considered. Influential teachers tailor the content to their unique groups of students, and finds ways to make it come alive:

> I'd say the one that probably always stands out the most was my human anatomy and physiology class. Just the way that teacher kind of brought it across… He just actually

> kind of gave us new and interesting ways to think about the human body, as well as the way some different diseases affect that. (BL)
>
> Mr. H_ was an anatomy and physiology teacher… He had all kinds of specimens, and when it came time to do dissections, he even caught a few live rats and let us, you know if you wanted to you could choose a live animal to kill and then dissect, and I did that (it was really fun!). I just got a real taste for how interesting science was and how fun. (AW)

The goal of the science teacher in communicating science content is not just to enable students to pass a certain test or meet a set of graduation requirements. Certainly, content mastery is essential for those who are going on in science, especially in view of the large numbers of students who drop out of the "pipeline" in college. But many students might not even consider a career in science if the teacher did not make the content relevant and come alive. This is illustrated by one who would know – a scientist *and* a dad:

> I really think that high school science teachers can have a huge impact on students' decisions of whether to stay in science or not. Particularly when they are thinking about where they're going to college and what they're going to do, whether they should go into science or go into something else. I say this because I have one daughter for whom one teacher I think really made the difference – her chemistry teacher. My daughter could have gone a lot of different directions. When she graduated from high school she wasn't certain that that's [science major] what she wanted. She had four things that she thought she wanted to do. But the science is right there, right smack in the middle. And the fun and excitement of that science, of that chemistry class, really made the difference in her final decision to go into science. (TA)

As the demographic data shows, not all scientists were “A” students in high school, and many of them did not even choose a career in science until well after high school. Students mature at different rates and their interests and directions change. In view of this fact, it is paramount for the teacher to not only provide an excellent background in science in the eventuality that some of them might go into science, but to also encourage the students who are unsure of their future vocation to keep their option open. In the author’s experience, very few students in high school actually pursue the career in which they thought they were interested. This point is driven home by the following scientist – *and* a mom:

> I think it’s really, really important to show how science is exciting, very relevant, and more so today than when I was in school. So, I think it’s crucial that the teacher shows enthusiasm and passion for the subject, and I would add respect for those things I wasn’t really wild about, like math… And I would encourage students that they don’t have to be a straight-A student. Not everybody who is in science has to be a doctor. No one until, boy, near the end of college, said to me, “you could just go into science,” or, “you could teach science; you don’t have to be a doctor.” Not that that was always my plan or anything, but you don’t have to be a fabulous student to enjoy or pursue science, and you can go a long way just by persevering. (AW)

Even though the next quote is about a college professor, it is just as applicable to high school science teachers – perhaps more so considering the fact that the college professor has a more mature (and, in advanced courses, more intrinsically motivated) audience. How can the teacher make the material relevant and come alive? How can the teacher make something they may have only read about in the textbook interesting? One of the most powerful ways to accomplish this is through the professional development of the teacher. As the author can attest after fifteen summers in various research programs for science teachers, the experiences, illustrations, and knowledge gained are inestimable and permeate the daily lessons:

> I think the course I took in groundwater hydrology – I can almost remember his name. He was a good lecturer, very serious most of the time, but he had obvious enthusiasm for science and I remember in particular when he started talking about his research work. And the enthusiasm that he had when he got to that. But he also introduced a lot of concepts that he had about groundwater hydrology I still remember. So that was certainly the most…inspiration – but I want to say inspirational – but informational course and instructor that I had. (MP)

Passion for teaching and science: challenge.

A recurring theme in the interviews was the importance of being challenged, not just for the sake of laying an adequate foundation, or preparing the student for college, but to stimulate, intrigue, and captivate the imagination. This is, after all, one of the ways to make a class interesting and relevant. It is arguably becoming a more difficult thing to do in light of what this author calls the "Sesame Street Syndrome." In other words, more and more students are growing up in a sensory-overloaded environment in which they are bombarded during much of their waking hours with images and sounds that last but a few minutes. These visual and audio vignettes require very little concentration, sustained thought, imagination, or reasoned response. This in turn makes the teaching of in-depth subject matter or complex ideas difficult. In other words, today it is a challenge to be challenging.

Yet many students relish and thrive on a challenge, and most would agree that the reward is great. The scientists appreciated working hard, being pushed and driven, and not being "spoon fed." They applauded teachers who were competent, demanding, organized, and engaged. A good teacher helps students achieve, even when they are out of their strength or comfort zone, as the follow scientist recollects:

> Mr. M_ was a physics teacher and he was also pretty “lit up.” He had a good time with it and so we got to do some pretty cool physics experiments. That was a little trickier for me because it was a lot less tangible than chemistry. You know there’s a force there, but what on earth is that force and how does that work? That was a little trickier for me. I know I got an A in M’s class, and I was pretty proud of that. That was one of the hardest classes I took. I liked it… I liked being pushed. I didn’t like boring classes at all. (DC)

Explanations and answers to deep-seated quandaries are not quick and easy in the “real” world, and certainly not in the science world, as they often are on television. In a culture that demands a quick fix and a fast answer, teaching students to wrestle and persevere, to live with the tension and frustration of not knowing the answer, is tough, but something that a good teacher must do. The following chronicle describes two long-range experiments students had to grapple with, one about a bottle that wouldn’t break, and the other about spontaneous generation:

> He was just kind of nice. He kind of played the nutty professor. Looking back I think he played that out. I think he enjoyed that role. He’d do goofy things now and again and he made that class kind of fun… He asked us if we thought it would break or just bounce if it hit the floor saying it was so heavy and so thick. He sort of obsessed on this for a couple of weeks and brought it up every couple of days and finally he made us all bet and he dropped it just to see what would happen – I think probably just to satisfy his own curiosity more than anything… I think he probably forced some sort of conversation or dialog about why we thought certain things would happen. And the other thing I remember about him was he did this long experiment one time… And he dropped the

> term spontaneous generation, and it was our task essentially over the course of the next month probably to figure out what really happened. And the interesting thing was we couldn't ever find a reference that said spontaneous generation didn't happen. There were plenty of old texts that said people used to believe this, but nothing that said people used to believe that the thing was not true, which I guess you don't find – I don't think textbooks often say that they used to believe it but it's not true. It's usually implied that if they used to believe it then of course it's not true. But he never would give it away, he just made us think, and I think that was what made that class so cool was he didn't just feed it to us – we had to think about stuff. (TW)

Passion for teaching and science: character.

The use of the term "character" here is meant to connote not just the idea that a good teacher is a role model endowed with positive characteristics (an *extremely* important component of good teaching that has been mentioned elsewhere), but that he/she *is* a character. Scientists frequently described certain teachers as being funny, wacky, kooky, wild, "out there," nutty, "lit up," nerdy, laid back, and goofy. Such demeanor is probably often necessary considering the competition from the media, and the too-short attention spans, especially in tougher classes with potentially drier, more theoretical material.

The idiosyncrasies that endeared certain science teachers were spontaneous, but they were also measured (under control) and designed to facilitate learning. They were never a substitute for covering the day's lesson plan or the result of poor classroom management skills. In other words, "being goofy" and "goofing off" are not the same things, as the following scientist points out:

> He was competent. Yes, he was. He was engaged and stuff. He'd try to make… it fun to learn. That was a class that you enjoyed going to. Not because you got to goof off, but because he was engaged in what he was doing. He'd make up stories and they were all lame sort of jokes, but it was the kind of stuff you let somebody like that get away with because he was obviously having fun. (TW)

Good teachers also know how to get the students to laugh *with* them, not *at* them. After all, a teacher who is not respected is not effective, and no amount of humor at that point will be able to generate genuine interest in the subject. Note how, in this next instance, the excited and funny teacher creates a learning environment that is exciting and fun – the classroom is the reflection of the teacher:

> One of those years, in eleventh grade I had chemistry with Mr. C_ and he was excited and exciting. He was kind of this wacky guy that just loved chemistry and had a lot of fun with it and we just caught on I think… Mr. C_ was pretty crazy, kind of a 60's guy with long hair, long gray beard, and he just had this kind of kooky, fun personality that we all enjoyed, and so his teaching was kind of wild and out there and we all got a kick out of that. There was nothing dry or boring about him, and I think that helped us enjoy class a little better. (DC)

In this last illustration, the scientist tells a story that might worry administrators and firefighters but certainly created a lasting impression. (For the record, there are many enduring memories that can be created without quite as much risk. Doing something outrageous or funny just for the effect is seldom wise, and endangering students no matter what the educational value might be is never justified.)

> But the year was good and in chemistry I am the type that I need [a teacher with] personality. And we had fun in that particular class. I admit that the teacher, who I can't think of his name, was so funny. He really drove you to see things to the best of your abilities… He was just funny. I remember one of the things that made the biggest impressions was early in the class he gave a talk about safety in the lab. And I still do this when I have new people working in the lab because it made a big impression on me and I want them to remember things, but we used Bunsen burners in the chemistry labs. When he was up there in the front of the class giving the demonstration saying, "You've got to be really careful when you're working in the labs. Safety first." But he's up there and he opens a jar of ethanol and he knocked it over on the counter and said, "Oh I'll get to that in a minute, I'll clean that up later." And then he went over and lit his Bunsen burner and knocked it over and caught the entire chem wall on fire and everyone is screaming and he says, "Don't worry, it'll burn out." And he did it on purpose but the point is that "Fix it as soon as you do it or something bad can happen." And it really did make an impression. I had a good experience. (DN)

Compassion for Students.

In the model of the pyramid used at the beginning of this section, all of the relationships were primarily between inanimate things (environment, curriculum) and either the student or the teacher. In this subsection, the relationship is solely between human beings – the student and the teacher. As such, it is infinitely more complicated by a host of variables that are often unknown and impossible to measure. But, as most teachers would agree, this aspect of teaching that contains the most mystery (and sometimes heartache) is also the most rewarding, and what teaching is ultimately all about.

In some respects, this entire chapter is about the relationship between the teacher and the student. Certainly that can be seen as an underlying theme in many of the quotes. All of the experiences and all of the prior relationships, both inside and outside of the classroom, forged during the lifetimes of both the teacher and the student, make each of them unique, and they now intersect. This encounter, in turn, profoundly affects both of them, and they are changed before they move on to other relationships.

Because human relationships by nature do not lend themselves to easy quantification, and because decades of additional relationships and experiences have been added since high school, the full impact of the relationship between the student/future scientist and the teacher is often never fully appreciated much less recollected. Sometimes only the more spectacular (or egregious) interactions come to mind, and the teacher's steady and quiet cultivation of the relationship and classroom environment is overlooked. Nonetheless, good teachers know they have made a difference, and this propels them. (See Appendix M for a list of synonyms and a table charting the scientists and the particular teacher-characteristics that they emphasized.)

Compassion for Students: care.

In order for the relationship to make a difference, it must be genuinely *caring* and not superficial. One scientist, who matriculated through school in a very hazardous environment with a small cadre of friends, was asked "Do you think you would have been as successful as you were if your teachers were more mediocre?" He replied,

> No, we wouldn't have been. It really was the teachers. We were passionate about science going into class, but we had teachers, gifted teachers who knew how to utilize information well, they knew our weaknesses, they knew our strengths. I think we would

> have still all have succeeded, but we would not have progressed at the rate that we did without the teachers there. They were certainly instrumental in moving us. (WR)

Crafting a classroom environment in which the teacher can discern the strengths and weaknesses of the students is an art. It takes a lot of purpose (intentionality) and patience to establish a sense of intimacy and collegiality among so many divergent personalities. This is perceptively described below:

> We went all through this class the whole year together not realizing we were in basically an honors biology class in ninth grade. And the teacher, he was an older guy, and not even terribly dynamic, but he would gather us around one of the benches, you know the lab benches, and he would tell us stuff like it was a great big secret. And we were all so thrilled, you know, to be in on these secrets! And we realized that other kids were not learning this stuff when we talked to them… But without us even knowing, he was giving us a love and excitement. I don't even know how you would quantify that or describe it, but we always felt kind of conspiratorial that way. (AW)

Compassion for Students: respect.

The second ingredient around which a strong student/teacher relationship coalesces is *mutual respect*. In the following assessment of good teachers, one scientist enumerates:

> I think I respected them for their science knowledge and that they taught a lot. Of course, I couldn't be very critical at that point but if they were good teachers or I thought that they were good teachers and the class was enjoyable, I respected that. If they were friendly and outgoing to students, I know I appreciated that and a lot of other kids did, too. If you would stop by after class or something – if they were just personable… Some of them would approach you and you would see them in other situations as well after

> school. Being accessible and personable, as well as being real confident in the classroom, all had a very positive effect. (DT)

Notice what is respected – knowledge, experience, confidence, being “good” at teaching, making the class fun, being friendly and personable, and being involved in the life of the school and community. This is certainly a tall order, but one that is happily fulfilled by many teachers. It is also proof that the teachers respect their students because the *teachers* do their homework (e.g., go to workshops and seminars in order to improve their skills and knowledge, conscientiously prepare for class, fairly and thoroughly assess student work, and set up labs and demonstrations).

It is not enough for the teacher to get to know the student. The student needs the chance to get to know the teacher beyond what is observed in the routine classroom interactions. This is accomplished in the following ways when (1) the teacher interacts with the student outside of the formal classroom (e.g., coaching, sponsoring clubs or extracurricular activities, attending concerts and games), and (2) the teacher shares about his/her life with the students. In the following story, a scientist fondly recalls his physics teacher:

> He was also in many ways a little more fallible than my chemistry teacher was, and in that sense maybe a little more human. Some of the things that he did were funny in class – maybe they shouldn’t have been to students, but they were. He was showing us how to shake down a thermometer one time so he said, “Be careful not to break them.” Well he broke the first thermometer trying to shake it down and it was little things like that that just made him seem a little more human than the others… He used to tell what I now understand as sea stories. He’d been in the navy in World War II and told sea stories. Things were just described and kind of a little bit of context around the class; it wasn’t

> just straight physics in his class, he had a little bit more of a – I'm not sure what it was – what today they would say it was more of a life than probably the chemistry teacher did. I mean that was my impression. Now that part contributed to my relationship there. (HH)

An important point is appropriate here. When the teacher shares anecdotes and stories, it should serve at least one of the following two purposes: (1) building relationships by giving the student a glimpse through the window of the teacher's past, and (2) promoting the curriculum by providing relevancy and context in a memorable way. It should never be merely the wholesale baring of the soul or the dumping of the teacher's personal problems on the student. (Refraining from doing this is one way that the teacher shows respect for the student.)

Compassion for Students: discipline.

Another essential ingredient (not unrelated to respect) at the heart of healthy student/teacher relationships is *discipline*, or as it is more broadly termed, classroom management. Again, as with respect, the discipline applies both to the teacher as well as the student. The teacher is disciplined by being consistent, professional, and under control. This becomes the foundation for student discipline, and the result is a classroom where all students believe they have a safe and fair environment in which to learn and grow. The following narrative describes such a situation in which the scientist – perhaps a bit of a trouble maker – is guided through this part of his adolescence by his physics teacher, and thus stays on track:

> He had a very strong character. He was loud. He didn't tolerate any goofing around in class, and didn't hesitate to put you in your place. These are attributes of a teacher in any class, not necessarily a science class. He was very much on top of things in his class. You couldn't goof around and get away with it. He was very involved and, at least as far as I know, he knew his stuff very well… He had a good interaction. I'd take the liberty

> of pushing my freedom in the class a couple of times and being reminded that, yes, he was the teacher. There were certain things I wasn't allowed to get away with, but overall I think that he was a very good teacher and enjoyed his work… Some days he took a personal interest in me but that was probably my own doing! No, I think he treated everybody the same way. He was truly interested in imparting his knowledge and sort of took the same manner towards everybody. Some of us who asked a lot more questions might have gotten a little more attention. He tended to be more vocal, cracking jokes, and things like that. I think he was truly interested in making sure everybody got the knowledge. (TR)

A second example of discipline (the scientist uses the word "strict") depicts teachers who knew their student's capabilities and what was best for him. They did not cower from their responsibility or give in to him but moved him forward. As was also shown in the previous quote, such constructive confrontation is only possible when a relationship exists:

> The teachers I enjoyed the most were my math teachers, the ones I had the most mathematics from, and the shop teacher who I did the mechanical drafting from. They were very strict people. As a result, I think I did a lot more than I would have normally…I actually learned a lot because they pushed me…I wasn't inclined to do that. (KT)

Compassion for Students: encouragement.

Perhaps the most recurring theme throughout this dissertation is the importance of encouragement in many different guises and by many different people. Suffice it to say, then, that the science teacher must especially be alert for students with a particular interest and gift in science. This comes through in the following two quotes. An interesting observation here is that teachers often respond commensurately to their student's interest, both in magnitude and direction. (Students would do well to remember this.)

> But the one in high school, Mr. F_ was the teacher, and I sort of got the impression that he appreciated my level of interest in the biological sciences. He cultivated it a little bit more… I could talk to the guy, and enjoyed talking to him, and felt like he cared about my interest in science. And my other teachers, I felt like I had amicable relationships with them but nothing special. (RC)
>
> Actually, I think that they all did [encourage me] to be perfectly honest. I know now – I substitute a lot at all levels through high school as well as at college – and I know now why I got that. If you're the 'A' student who is giving it the effort, you get the extra attention. And my God, I got a lot of encouragement and attention. I was always well treated and encouraged. I got letters of recommendation for college and I got help with figuring out which classes I needed in college. (MH)

Compassion for Students: involvement.

For many students, their most memorable adult relationships in high school were with coaches. The teachers' involvement in extracurricular activities affords students the opportunity to get to know their teachers better and for teachers to get to know some of their students better. This deeper relationship enables the encouragement and discipline to be more personal, as the following two reflections show. (Incidentally, the smaller the school, the more this is possible. In a gigantic school, a teacher could be a coach and never even see one of his/her students participate.)

> I think the fact, with Father B_, for example, that he was a coach made it a lot easier to interact with him, because I ran track and cross country, so that made it a little more

> informal than for other students in the class. It might have been tougher for people who didn't do sports to interact with him in the classroom. (FR)
>
> I went to a medium to smaller sized high school, so you could know the teachers pretty well. And they seemed to be more involved with the students; they liked to sort of talk to you outside of class and all that kind of stuff… I think that's good too, because certainly, if nothing else, if you know this person a little bit, as a student you will be willing to ask them questions. Otherwise you're not going to. (JI)

Not all science teachers can coach or sponsor clubs. Sometimes just being available after school or creating opportunities to assist in lab preparation or other projects is conducive to strengthening relationships. For example, one scientist quoted earlier (HH) was a teacher's assistant. As the author has experienced almost yearly, the teachers seldom choose who will take a special interest in them or their subject, but when a student does, the teacher must be ready to reciprocate, even if it means to creatively invent some project for the student to accomplish. Here is an example:

> I do remember physics [teacher] because I had a lot of discussions with the fellow on physics...he was much more mild mannered, but we still managed to get along and had good discussions together… Mostly after class I used to help in the preparation of things… I went in and said, "What can I do?" It was nothing formal. There wasn't much to do – we had very little props, mostly paperwork. I had a set experience with electronics, so I could do anything electronically. (KT)

As has been demonstrated, in order for relationships to thrive and prosper, a commitment of time and energy is requisite. Often the rewards are not patently manifest, but sometimes they are, as the last two anecdotes indicate:

> I think it was that my teacher, he saw my interest and everything, he's the one who said that I should apply to UCLA…my physics teacher…because I wasn't even going to do that…that was a turning point, because I started to think maybe I could do that. (KT)

> I had an opportunity a couple months ago to go up to a high school in Northern Idaho. They have a teacher there who manages part of the science action team here and we went up and we took him out field sampling and it was maybe a couple weeks after school was out and we saw seven students who came on their own time on their summer break, some of them had even graduated, to go field sampling because they really liked the guy, and therefore they like the science. I think that is important. (DN)

Negatives.

Not all of the scientists' memories were positive. The purpose of this segment is to flag those situations, behaviors and traits that are potential impediments to progressing in science (or other fields, for that matter). Obviously, because those who continued in science tell these incidents, they were not so substantial that they could not be overcome. Most likely, not all students were so fortunate.

Several scientists recalled teachers that weren't present in the classroom enough because of other responsibilities (e.g., coaching), illness, or pregnancy. In the following two examples, not only were the excessive absences a detriment, but the preoccupied demeanor of the teachers, though understandable, severely interfered with their instruction when they were in the classroom:

> The chemistry one wasn't very good at all. And I do have to say that my chemistry teacher was in the midst of trying to start a sort of gifted program for students. Our class turned out to be in the afternoon so she actually was not in our class as much as maybe

> she would have been a year or two before. So we ended up getting substitutes quite a bit and I think our chemistry really suffered… a lot of times it was when the lab was scheduled and so she would have someone else sort of come in and get us going. And you know the high school mentality wasn't "Let's get the most out of this lab." (JI)

> My final year of high school I had an AP Chemistry class that the teacher just was not engaged in at all. She really didn't want to be there. She was pregnant and they were re-flooring the gym with some kind of nasty chemical, so she took three months off because she didn't want to be in the building. And it was medical leave, but it was because the building stunk. And it probably wasn't a safe place for kids to be because you could smell it… So she took a bunch of time off, but it didn't really seem like she was interested in being there. And her teaching style was, compared to all these other teachers, it was really not that engaged. She just sort of lectured about stuff and had you do experiments. And perhaps you're supposed to be more self-motivated in an AP class, but it just seemed like she could've done a better job. (TW)

Sometimes the teacher is *physically* present in the classroom but not *mentally*. Regardless of whether the reason was a character flaw, personal issues, or poor teaching skills, the consequences would be the same – a negative learning experience that could have resulted in dropping out of science altogether, or in the following case, changing sciences:

> I guess it was disappointing that my chemistry teacher wasn't really focused on teaching chemistry at least that particular year. And really, to be honest with you, that was probably why I didn't go ahead and take any more science [in high school], because it was a pretty mediocre experience. (JI)

No teacher is perfect. But sadly, some teachers have enough weaknesses (or one big one) either in personality or ability, that teaching is not the best career fit. Somewhere along the line, whether in college or early in the teacher's career, a professor or administrator should have suggested a career change for the teacher's own sake as well as the sake of the students. A scientist describes a teacher who might fit this description:

> He knew his stuff really well. And yeah, he was a good teacher because he was able to mix the lecturing with the demonstrations very well. At the time because he was so different he was an odd ball, an odd person, a very different kind of person. For some of those students it didn't work. They were too alienated by his character. I suspect most people respected him a lot as they got older and realized what they had. At the time that was not the case. He was viewed more with fear and trepidation because you've got to do physics and first you've got to pass so you were going to have to do all of this hard work and of course he was going to make you do it. He didn't provide the [encouragement]… He wasn't a role model for anyone in that class in the sense that someone would look at him and go, "Yeah I want to be that guy." He was just too odd. (TA)

Much has already been said about the importance of a teacher showing enthusiasm and excitement. The following two quotes are juxtaposed around these traits – too little and too much – and beg the question, "When is the flaw too extreme?"

> He was a nice guy but he was sort of a stuffed shirt. His level was very monotone, his voice, such that you never got a hint of what was exciting or what excited him, or what might excite you. I think he was competent as a teacher, but just didn't provide that level of enthusiasm that gives people an interest in the subject. (TR)

> [He was] very volatile. On a Monday morning I can remember distinctively that they had had a bad weekend and the team had just lost miserably. And all of the homework was tossed out the window and I'm like "Oh, no!" He was too emotional to maybe teach and coach both. And then again his style of teaching I didn't like at all. It was simply he would chuck on the board the example in the book. Talk about people that maybe shouldn't be teachers… (JB)

When the connection between student and teacher is not made, it is sometimes difficult to tell who is to blame – if either, or maybe both. For example, one scientist, admittedly predisposed to being a discipline problem, describes a teacher he liked, but:

> Mr. L_ was pretty boring. He lectured most of the time. He was a really short guy so you could barely see him up at the front of the room, he was really little and kind of monotone and pretty much just lectured until we had a lab and then we were just mischievous fifteen-year-old boys so when we were supposed to be dissecting something we'd be chopping it into little pieces and carving our names into it or something. I ended up in detention usually. Something about that class didn't work. (DC)
>
> But to give you an idea of how unexcited about it I was, that whole year my big accomplishment was: I could hold my breath in the beginning of the year for something like fifteen or twenty seconds and I had it down to two minutes by the end of the school year. And that's how I spent class a lot was timing myself. I would sit and hold my breath and time myself. I had no interest in what he was saying. And then I'd cram for my exams and move on and that tells you where I was at. (DC)

In the same way it is sometimes difficult to tell which came first, the student's dislike of the subject because they dislike the teacher, or the student's dislike of the teacher because they dislike the subject:

> I don't know if it was necessarily that I didn't like chemistry and physics so much in High School because I didn't necessarily like the teacher also… Maybe that goes back to not being all that fond of math anyway and I think physics and chemistry have to use a lot more math. (BL)

One negative factor that stymies enthusiasm and destroys a healthy learning environment is excessive pressure and tension. This can be self-imposed or it can be generated by the teacher. When two scientists were asked if they endured any discouraging times in their science classes, they answered:

> Oh yeah, many times. I don't know what they all are, mostly probably pressure for grades, which is placed upon me by me. I was pretty sure I was able to follow along and stay with the class, understanding the stuff at the same time. Get your stuff done, pressure's off. In terms of general experiences, science has always been an interesting thing to do. Whether it was or wasn't, or whether I was or was not engaged didn't matter, just do it. (BM)
>
> Well, the professor got up and said, "Now I know all of these guys are just taking this class; they're not majors; you're not physics majors; you're just taking it because it's a requirement. And so I'm going to tell you right now that 60% of you a C or a D. 10% of you will get an A, 20% will get a B, and the rest of you will get C's and D's and F's." He showed no excitement, just competition. It was straight competition and no real love for the field. (AW)

Sometimes a teacher can be a good teacher, but not a good science teacher. Fortunately this was not the case for the following scientist, but does point out the fact that, too often some science teachers are coaches who, because they had some biology-related classes in college as a part of their physical education majors, are given the responsibility to teach science. In other words, they were hired more for their coaching abilities than their teaching abilities. They know it and the students know it:

> Another thing that was memorable was that my physics teacher actually had a degree in physics and I think it might have had more to do with the Vietnam War during that period of time. [Being a teacher kept him out of the war.] He was only at my high school for a few years. It was sort of unusual because usually you had the coach/science teacher model in the south and I didn't have that. (JP)

This same teacher had two other insights about her high school science teachers. In the first case, her science teacher had lost his "first love." In the second case, science teaching was perhaps not her teacher's first love. What subtle effect this tepid and divided interest may have had on the other students can only be imagined:

> The chemistry teacher had been there many years and I think he knew his subject matter but probably was not quite as inspiring. I think he might have just been going through the motions but part of it was that he had just done this so many times. It wasn't new to him, and the other two people were early career people, so they might have been a little bit more inspiring in their early career… I think that most of these people, the biology and the physics teacher were going to go and work on additional degrees and teaching might have been something of an intermediate. I guess they aspired to be real scientists

> rather than just teaching science. I would classify all these as good teachers, though. (JP)

Finally, and arguably more insidious than those teachers who are somewhat incompetent but at least try to do their best, are those teachers who should not only not be teaching science, they should not be teaching anything. These are the ones who, by their actions, demean and belittle the profession in the eyes of both their students and the public:

> I would say in the teachers I've been looking at now, and even the scientists here and things like that, some would come here and do this whether you paid them or not. Others are here only for the money or do only the minimum amount required. The High School teachers I had were more in the category of they will show up, they will do what they do. But they're not going to go much beyond what they have to do to get their paycheck and wherever else their interests lie. I don't remember them really going out of their way to really make something super interesting. (EM)

Influence of Pedagogical Practices

As was stated earlier, it is extremely difficult to separate the influence of a teacher from the influence of their pedagogical style and practice. In other words, it is the "complete package" or synergy of relationship, style, and personality that can positively energize the prospective scientist. It is also true that most teachers will employ a variety of pedagogical practices rather than sticking to one approach exclusively, though a single style may often predominate.

Of course, few students are even cognizant of their teacher's formal pedagogical approach and strategy *while* they are in the class. They simply know that they "like" the teacher or the way the teacher teaches. Only years later, perhaps when they have taken some education courses or have children of their own in school, do they occasionally discern the methodology that was undertaken. Nevertheless, many of the scientists were able to distinguish particular teaching practices and comment on them.

Most of these comments center on the terms *demos* (demonstrations usually performed by the teacher in front of the class), *labs* (formal laboratory experiments conducted by small teams of students according to some prearranged protocol, e.g., lab manual), and *hands-on activities* (usually less formal and less structured than labs, though not altogether distinct). Other teaching practices include the more conventional lecturing, story-telling, and special visiting – either going outside of the classroom on a field trip, or having someone (or thing) coming into the classroom, e.g., guest speaker or exhibit.

Demonstrations.

The value of demonstrations is undeniable because they make real the theoretical. A mental image based upon a verbal description may contain false information and perpetuate naïve ideas. Long after the demonstration (often truncated to "demo" in ordinary conversation) is forgotten, the concept that it clarified endures and can become the firm foundation for further understanding. This point is captured by the following insight:

> I really think that demonstrations are important and though I can't recall individual ones, I know there were a lot of them. And even now I think that [a demo] is really the thing because you can [merely] read about something but it is not real, not tangible, doesn't really mean much. And so I think that demonstrations are really important. (DN)

Those scientists who recalled the demonstrations that their teachers did were constructively critical of them (the demonstrations). As one scientist noted, "I think demonstrations are really important as long as… number one, they have to work. I think it's bad to do a demonstration that doesn't work and then have to try to explain what should have happened. It loses kids really fast" (TA). A second scientist adamantly pointed out several additional concerns, including the constraint that demonstrations should support and illustrate the curricular content, not *be* the content. In other words, you can have too much of a good thing (demonstrations), to the point where it can be counterproductive and actually detract from the learning process. He recounts:

> My physics and chemistry teachers used more conventional teaching methods that allowed us to forget much of what we were supposed to learn during the course of the year and were not focused on critical thinking skills. In chemistry, we had too many demonstrations ("Mr. Wizard" type demos where we would see a solution change color, or precipitation occur, etc). These were fun to watch but rarely involved any participation from the class. What we learned of the basics of chemistry didn't appear to stick with us very long. In later conversations with classmates who took chemistry in college, they all agreed that they felt inadequately prepared for college chemistry courses (as I did)… I think the problem was that they [demos] were just kind of isolated incidents, that there was no connection between one demonstration and the next one; they didn't seem to have anything to do with what we had learned in the previous demonstration. It was kind of an isolated thing where he would show us something we would be impressed with. We might have been impressed that day but then the next time we did a demonstration it didn't seem to have any relationship with the last one, at least not that I could recall. It just seemed to be unique things, in and of themselves, we were impressed with that didn't relate back with the text or to what he did next. (DT)

Another scientist concurs, adding the concern that a good demonstration should not take too long, nor does it have to in order to be effective. It doesn't even have to be complicated, dramatic, or profound. She opines:

> In my opinion, I think that if the demonstration really does show a point – I know just in other learning situations in college and also taking training classes – sometimes the demos that people have take a long time to get rolling, and maybe there's some point in there…but it takes too long. I think it has to be something that hits the teaching point as opposed to just doing a demonstration to just "ooh, aah" the kids. I had one in junior college that still sticks with me. The guy who brought in long spaghetti and thick macaroni was trying to talk about the difference between something having the same molecular weight but being a long stringy type of molecule as opposed to something that was more compact so structural. And you know, that was just a visual and he was flipping it around while he was talking to you, but it was something that stuck with me because you sort of lose sight of a molecule when you don't get to physically see it. You know those types of things are good where they're not necessarily exploding things or making color changes… something real dramatic… but something that is going to stand out in that sense. (JI)

The last quote in this section is interesting because it seems to illustrate, on one level, exactly what the previous scientists were warning against. In fact, halfway through the recollection the scientist realizes that he has the demonstrations confused. But sometimes the value of a demonstration is not so much the content it conveys. Instead, it serves the *short-term* purpose of incubating an interest and excitement about science in the student at a time when there are so many competing interests clamoring for attention. It serves the *long-term* purpose of creating a vivid memory that reminds the scientist about why they pursued a career in science in the first place:

> He [chemistry teacher] had the monkey shooter [a classic physics demo], and I don't know how that fits into a chemistry class – I think it's a physics thing – but he definitely had the monkey shooter because I remember we played with it one time, and that was pretty cool. I thought experiments like that – he had the monkey shooter and the dragon's breath – and the dragon's breath [a chemistry demo] is just powder. It's a combustion of dust essentially, and if you find enough powder it will burn. So he collected dust bunnies and stuff over the course of time, and he blew them through this orifice, and it just exploded in a really brilliant but short-lived kind of fireball. But, no, it was within a can – that was it – it was all in a can and it just blew the top off and flames shot out, and he'd pull somebody in from the hallway like a football player and say, "Hey, I want you to breathe into this thing, blow as hard as you can," and then you know it wouldn't hurt anybody, but it was to prove a point. And so he did things like that. (TW)

Labs.

In the previous discussion about demonstrations, the scientists basically made the point that what is important is not whether or not a science teacher *does* demonstrations. What is important is whether or not the demonstrations are *meaningful*, e.g., there is a point, they are relevant, they don't take too long, and they are not merely for entertainment's sake. The scientists make many of the same claims about laboratory activities. For example, two scientists comment on the fact that sometimes the lab experience is more like following a recipe than actually doing science. The downside is that, in the first case it doesn't teach very much, and in the second case, it can be an intellectual "turn off" and, therefore, counterproductive:

> We had lab once a week… and then we had these work/lab sheets that we worked on, that we would do certain little things…They were okay. I thought they were too simple – I didn't learn enough from them… [they were] short and easy to do. You could see the end, you could get there in a fair amount of time…its just a matter of doing it, it takes a number of points and you're done…very "cookbookish." (KT)
>
> The big downfall of the cookbook method, in my opinion, is that it's very easy for a lazy student like me to simply follow directions and just turn my brain off, and that's what I did. I mean, there was all this introduction that explains it, but step one: add this dye. Step two: if it turns blue, you've got starch. Step three…you know, whatever… Very meaningless to me. So the cookbook one, you've got to find a way to engage the kids' brains, and lazy students like me turned off our brains when we had a set of instructions that we could very clearly follow, get the answer in the end, and get out of class early. (DC)

This same scientist points out, however, that just because a lab is not "cookbookish" but more open-ended and investigative, it should still yield decent results. The pendulum should not swing too far in the other direction, at least at the formative level of high school:

> I think that the types of labs students need, and I think this carries into college, especially in the freshman and sophomore years of college, I think the labs students need to see are ones where they get clear results, where the results are not muddled or ambiguous. Ambiguous results, ambiguity, in the labs, I think is a big turnoff. Granted, in the real working world, there's a ton of ambiguity you have to deal with, working in a lab, but

> that shouldn't be used to teach or fire up the students. I think the students need things [experiments] where they're going to get data. (DC)

The importance of doing labs before college should not be underestimated. Like math, it is an essential component of future success in science in college, where too many students drop out of the science and engineering track. Fortunately, this next scientist merely switched sciences rather than fields:

> I didn't enjoy physics very much… I think that probably was because we didn't actually do too much lab work. I do recall doing some classic friction experiments and optics experiments, but I think that most of what we did was calculation and that didn't really turn me on to physics. I think that carried over into college, too, because I recalled not enjoying physics in college. Now you take the general undergrad physics and upper division physics… [In] chemistry I actually had a lay teacher, a woman… and I really enjoyed chemistry. I think part of it was that it probably had more labs than any of the other classes I had. (FR)

As with demonstrations, the lab activity becomes substantially more meaningful when it does not stand alone but is integrated into the other parts of the course. If the lab is important enough to consume class time to do it, then it is important enough to be included in the evaluation, as the following scientist implies:

> The biology class actually was pretty good. We did all the mandatory dissecting of different animals… I remember some of the tests where actually he would have something dissected and you would have to go up and look at the frog or whatever and name the parts. Or you had to physically do something that had to do with the class. And so I think that, in that sense, it was actually pretty good. (JI)

The evaluation of a dissection lab may be relatively straight-forward, but other labs sometimes require a more creative and multi-pronged approach, as this next scientist describes. Note that the lessons learned are more than just about "what happened" but include gaining an understanding about the process of science itself and how the lab might apply to other situations:

> They [the labs] were pretty much standard but set up so that you could extrapolate what you learned. And so thereafter Sister C_ was very adamant about after you finished the lab, the next day in class she would say, "OK, this is what you did, what's the principle and then let's talk about other situations – what similar kinds of reactions would be expected? And so it wasn't so much structuring a hypothesis type as "OK, I understand this as it related to the lab exercise. Can I take it and apply that knowledge to new, unknown situations?" Her exams for us did that too, because the exam questions would be looped [connected to the labs] and you'd have to think, "Oh gosh, I did something like this in labs….how would I approach this unknown or something?" – again trying to make you think. And I think that was the basis of her whole approach: make the students think, because, if they think, they remember. And I think that her style of teaching would be a style [I would use] if I was to ever teach, because it was so much fun. (JB)

If and when all of these stipulations are adjoined to the lab activity, it becomes a formidable and influential learning experience. Unlike demonstrations and hands-on activities, however, in labs there can be a more substantial writing component that takes a lot of work, and is generally not appreciated until years later:

> Yes, I thought they [laboratory notebooks] were very valuable. That was one of the more valuable things I think I did in science class, that helped me later on anyway, because it made me- made us- think of exactly what we had done. It's really easy to go through a

> lab and, if you don’t write something, down you don’t remember it, you don’t learn from it. Plus it taught me a lot about the scientific method; just generally putting it into practice, anyway. You know, writing down a hypothesis, what we were doing, did we answer that, did we not, what kind of results did we get, just recording it so that you could look back and repeat it sometime later on. And I think something that is really important about a lab notebook is being able to go back, look at what you did, and having written down enough, that you can actually redo it if you want; or somebody else can look at your work, understand what you did, and repeat it. So I thought that was very valuable, well worth the time. I remember not particularly liking it. As a student, it seemed like a waste of time and a lot of effort with very little outcome- practically speaking, for us. Looking back at it, I think that was a very valuable thing. I know other people that have said the same thing. (DT)

This writing takes time and effort, and is part and parcel to science, but is too often the very thing that turns many students off to science or causes them to avoid the courses altogether. The challenge to the teacher is to make the writing palatable, and to help the student see the bigger picture, especially if the student is used to being entertained or has a minimal work ethic. Foundational to this, in turn, is the issue of *trust*. Does the student trust that the teacher knows what she/he is talking about, and has the teacher earned that trust by demonstrating those characteristics described in the section of teacher-influences? Trust is a product of an established relationship.

Hands-on Activities.

Hands-on activities bridge the gap between demonstrations and full-fledged laboratory experiments. However, it is often impossible to tell when a demonstration becomes a hands-on activity as students huddle around some gadget or device that a teacher is using to illustrate a scientific principle. One scientist's description of his physics teacher illustrates this:

> He had hands-on stuff all the time. Maybe that's easier in physics, I don't know. He always had widgets, and we were always crowding around while he'd do some cool thing with a widget to demonstrate some principle. *A widget?* I don't know what kind of widget. Just some little engineered gadget that demonstrated some principle of physics. It was pretty cool. I enjoyed that. I remember dropping stuff out windows and looking at the rate of gravity maybe with two things that have different masses or resistance, two different sized balls, things like that. (DC)

It is equally impossible to tell when a laboratory experiment is brief enough or informal enough to be classified as a hands-on activity. Indeed, all laboratory experiments are technically "hands-on" by virtue of the fact that the students must handle the attendant beakers, carts, and dissection implements. (This would not be true, of course, if the lab activity is *virtual* because it is a computer simulation.) Reciprocally, all hands-on activities are (or should be) experiments in which the student is investigating some physical phenomenon and testing ideas, but without the rigor of recording procedures or data. In any case, as the ensuing remarks will show, the benefits and cautions that are true for labs and demos are true for hands-on activities.

One advantage of interviewing scientists is that they often perceive educational practices in surprisingly insightful ways – ways that are untainted by the influence of educators and their theories and jargon. The following description is an excellent example of this, and shows again that what happens in the classroom does not happen in a void but is embedded in relationships. Such relationships are three-fold – they should be part of the rest of the curriculum, they should relate to the student’s world, and they are predicated upon personal interactions with the teacher and classmates:

> You might even say that what the hands-on science stuff does is it causes the instructor, the mentor, and the student to come together in some situation where there is going to be an inspirational event. That, where you know the student says, “Aha!” and the mentor says, “I saw it! You got excited!” and then they’re excited together. As opposed to the lecture situation, even if somebody is a good lecturer, if it’s not a dialogue and it doesn’t involve some sort of progression and then the “light coming on,” then it may be bound to be sort of distant…that interaction. So you could almost say or form a hypothesis I suppose, that hands-on science just melds two people together, or a group of people together, and that is an exciting part of science. (RC)

Relating a hands-on activity to the real world is not hard, but does require some extra work and planning. In the following example, the teacher accomplishes two educational objectives at the same time, a fact not lost on the scientist as she ponders the question about what was missing in her high school science instruction:

> I think some real world experience, you know, maybe. For instance, I remember in college doing a very simple activity where we went to the local pond that was in the quad, and sampled and took back that for our microscope to learn to look at microbes when we were doing the microscope stuff. As opposed to the slides that you purchased that are exactly what you say. You know, frog cell… Those don’t teach you anything “real world.” You’re learning to use a microscope in high school, but you’re not learning anything other than that. Whereas, when we went to the pond, I saw all of those things

> that were living right there in the pond. It made more sense to me and I think we could have done more of that in high school. (MH)

Not only should hands-on activities (as well as demos and labs) *relate* to the curriculum and *be relational* (promote relationships), they should be but one part of an arsenal of instructional strategies that the science teacher employs. When blended with other pedagogical approaches, each potentially makes the other more effective, and helps to ward off the tedium and boredom that students usually experience sooner or later. One scientist, referring to his high school physics class, recalled that:

> There was probably more time dedicated to experimental work and lecture and problem solving through bookwork. Everyday the theme was simple sorts of experiments, [for example] measuring potential energy by climbing a set of stairs and running down them. Things like that, things that demonstrated simple physical principles but kept you very involved and were kind of fun. You're not [merely] thinking [about], you're learning physics when you're climbing stairs but his method of teaching [promoted that]. (TR)

Many factors determine whether or not hands-on activities (or demo or labs) will be effective. These include the learning style of each student, the teaching style of the instructor, and the physical resources of the school. When these mesh, the results are far-reaching, as the following analysis by a scientist of her son reveals:

> But his experience in high school: there were several teachers that really inspired M_ and I think in a way some of those teachers maybe were an influence in him deciding to start in engineering. And it was a teaching style and I know other people really loved the style, but for M_ – he's very interactive/hands-on and kind of hyper, and then again the

> classes he loved were those that were very interactive. So there's an example I guess of where teachers and their teaching styles made a difference. (JB)

Clint Eastwood once said, "A man's got to know his limitations" ("Magnum Force," 1973). In other words, in the context of this discussion, a wise teacher knows those pedagogical areas in which she/he is weak. A wise teacher also knows that some days he/she is not up to the task, whether because of illness or other issues. The following observation demonstrates that the effective use of hands-on activities (or demos or labs, for that matter) can help to ameliorate such shortcomings. Recalling a teacher that was just not very enthusiastic, a biologist writes:

> It's kind of funny – it goes back to the whole physics thing, and just relates to building bridges and bridge structures out of balsa wood and then going down in the main area of the school and seeing how much weight they could actually support … and it was kind of interesting. (BL)

Of course, as with any teaching technique, there is a wrong way to exercise it:

> The other side of it is that teachers who are forced to do hands-on science…the kind of effect that has in the end on the kids: "Well we're going to do this today. Don't make a mess, I'm telling you *don't* make a mess. Okay, we're done now, we're done. Put everything away." You know, did that hands-on science do anything? (RC)

Hands-on activities, by their very definition, imply that there is *stuff* (substance) upon which the students can put their hands. Often this requires special equipment that can be quite expensive both to purchase as well as to maintain. When the resources are insufficient, the experience that could have been transforming might be more than just cancelled out. It might have such an adverse effect that compensating for it in the future might be impossible.

> Even things as simple as looking at things under a microscope. A lot of people never have that opportunity, or they *think* that they have had the opportunity. But when I have helped out the school locally, you can't see anything because all of the microscopes are in such disrepair. But, I mean, it's very frustrating. So, I think hands-on [*operational* equipment] is the thing. (DN)

Perhaps the only thing worse than *not* having a certain science-related experience (because of a lack of resources) is having a *negative* one. How often this happens because a well-meaning grant, for example, that begins a program or provides valuable resources, but then does not continue during the less glamorous years when the novelty wears off or maintenance is needed, is unknown.

Other Practices.

A good teacher may be entertaining, but a good teacher is not first and foremost an entertainer. As several of the scientists have already indicated, entertainment for the sake of entertainment is detrimental in the science classroom. Certainly, it is all too easy for a science teacher to think of himself/herself as an entertainer while doing demonstrations in front of the classroom. But, when the teacher uses entertainment (or their style is productively entertaining) as a vehicle for communicating important principles, then quality learning transpires. One way to stimulate thinking and imagination is by telling stories. An example of this is conveyed in the following account:

> I think it was the stories. We'd go through and he'd bring up situations—you're on a desert island, and you're getting colder, and they left you off with all your science stuff, and you're going to do some maps, or some measurements on something. And suddenly you realize you don't have a scale. You forgot it, and there's no way to call them back.

> Three months until they come pick you up. What are you going to do to have the weights of all those different things for those three months? I got more intrigued in that type of issue. You know, it is good. This way it brought you back to some real basic principles—how do you weigh things? Which brings you back down to a graph and math, and a lot of other things. It brings you back down to something that, maybe you look at a problem quite differently. I found things like that more intriguing. (EM)

Just as a television show might have a guest appearance by a famous entertainer, or an orchestra might have a guest appearance by a famous musician, science teachers can sometimes call upon a guest scientist, either by going to visit them or having them come to visit the class. This approach also works for famous places. The class can take a field trip to a museum or park, or the museum or park can be brought to the classroom (e.g., video). For most of the scientists, this experience took place on family trips, and few shared in any detail about their school field trips (which usually took place in elementary school) or the times when they had special speakers or movies, with the following exception:

> Again, I think it's the teachers really showing us how much was out there and how fun it was! That's such a small word to use, but that it was interesting and exciting and there was so much to learn and so many places you could go with it… I don't recall exactly if they all did this, but I think a lot of them brought in outside professionals. And again, I'm having trouble recalling, but I know we went on a good number of field trips in the biology class and had interactions with other people who cared, who enjoyed science. (AW)

Teachers must always make judgments about the wisest use of class time, and field trips often necessitate that the students miss class, including all of their other classes. They also require a tremendous amount of making preliminary arrangements and supervision, if not expense. These difficulties are exacerbated by the increased focus on meeting curriculum goals and preparing for standardized tests. As is often the case, time is of the essence.

The next thought in this section derives from the fact that teachers must have a *vision* of the big picture, and the ability to enable students to buy into that vision, even though by nature and age students cannot be expected to comprehend what is in store for them. It is all too easy for a teacher to do those things that give the students immediate gratification, and it certainly makes that teacher more popular with the students (and, sometimes, parents and administrators) even though it is superficial and short-lived. Good examples of this are found in the next two quotes. In the first, a Socratic/didactic style is effectively used to generate some discomfort early on but sets the tone for the remainder of the year. In the second, a life skill (as far as academics is concerned) was the fruit.

> I was highly influenced by the approach my biology teacher used. On the first day of class, he asked the class to look out the window at a tree and pretend that there was a dog standing next to the tree. He asked us if we could distinguish the animal from the plant. Of course we all said yes, but then he started a series of probing questions, always coming up with exceptions to every reason we could give him on how to tell the two organisms apart. He left us very confused that day and convinced that we knew almost nothing about the subject of biology and very reluctant to volunteer to answer any subsequent questions. However, he built on that approach and spent the rest of the year teaching us how to ask questions, how to build and defend hypotheses and how to think in a scientific manner. Along the way he taught us a great deal about biology. Looking

> back at his approach, I think it was the most valuable of my experiences in science classes in high school. I ended up majoring in biology in college. (DT)

> But when he started the year, he had all of his notes written out on an overhead, and he would make an outline and talk to us about that. He said, "One of my goals here is to teach you how to take notes in a science class." So, as the year went on, he had less and less up there but he would help us find a structure, and he set that up and would make sense out of the lecture, because of its structure. And I used that all through high school up through college and graduate school without realizing it; he had really taught that to us intentionally. And that was a big help. I don't know if that would have occurred to me to set out and teach that. It was very helpful. He was just dynamic! (AW)

The final observation is to reiterate that each pedagogical style serves a purpose but should not be used exclusively. For example, certain information must be learned by rote – there is not always a more engaging way to commit it to memory if, indeed, it must. Some students are adept at memorization and can find an entry point (and some success) into science through more pedantic and formulaic approaches, as the following indicates:

> And chemistry was a little more objective it seems, a little more black and white than biology and I think I did better in that class. When somebody throws out facts at you and tells you to memorize those facts and integrate a number of constants I did a lot better at that than at getting stuff where there was a little more "loosey-gooseyness" like in the life sciences. So I really enjoyed things like redox [reduction/oxidation] chemistry where you talk about how an electron goes from this atom over to this atom and how everything changes once that happens and I'd get a kick out of that and I sort of understood that. We

> had to memorize the periodic table and memorizing, I could do that – that was great. I really enjoyed that class, pretty sure I got an A. That one was fun. (DC)

But, as this last example illustrates, even though a certain pedagogical style might work because it matches an individual's temperament and learning style, it is not necessarily the best approach for the rest of the class. Other students may not be good at memorization or the more perfunctory approaches to instruction, and there needs to be the more open-ended and investigative activities ("loosey-gooseyness") for them. Besides, science teachers teach more than just future scientists – they also teach citizens:

> They understood what they were teaching, and very well, and they knew how to teach… The teaching method was the standard drill and return, drill and return in a lot of cases. And that to me is a good way to teach it. Because that's what it is and you have to know it by drilling, and they were willing to drill it in the classroom to get you going and then send you home to drill some more which was fine. *And in the drilling, how did they deal with some of the students who perhaps did not want to be in the class?* They were ignored, they were left out. And they would leave the class. (EP1)

Influence of Mentors/Role Models

Often, and ideally, the young scientist has an outstanding mentor(s) to accompany great parents and teachers. This role model, as the literature review showed, is often encountered through a summer research internship or some other science related experience outside of the formal classroom. In lieu of effective parents and teachers, the mentor then becomes the essential relationship that enables the student to overcome obstacles and capture a vision of a career in science. Such an individual is described in the following assessment, and exemplified in the second one. The particular constraints that women in science must often confront are addressed in the third quote:

> I think it really helps to have a good role model in the area that you are interested in. It just gives you a much better feeling or perspective. You can look up and respect these people – it naturally makes you – if you are interested in that [career] – feel good about pursuing that. Whereas if you have someone who is a negative role model it can steer you away from something that you otherwise might like. (DT)
>
> My first job at age 14 was working on a cleanup crew at a machine shop that utilized a crew of young (mostly college) men. My father was the supervisor for this crew and he paired me with a college student who was studying Physics at UCLA. This person and others on the crew were a great resource of intellectual discussion for me that opened up my horizons a great deal. If it had not been for this person, I never would have applied to UCLA for college, thinking it was beyond my reach. (KT)
>
> Now I think about just being a woman in science. It's definitely harder… in that there are very few role models if you want to have children and continue a career. Coming here, J___ was one of the few women I knew who was still really active and still had a full family life. And I think it's discouraging, trying to balance both. (YF)

Influence of Peers

Peer pressure can be positive or negative, whether one is in school or in the workplace, or whether one is focusing on science or focusing on any other endeavor. Negative peer pressure can be formidable during a particular time of life, because of a particular cultural influence, or because of a subset of the local population. For example, several scientists commented on the difficulty of getting through adolescence.

> I got excited and interested [in science] in seventh and eighth grade. I got into high school, and social pressures and such became more important than classes, and so I wasn't all that passionate about anything in high school. I lost that excitement that I had in junior high… I think I was excited because the science itself was exciting: I could grasp it, it was somewhat objective, and it was really cool and crazy. Who ever would have thought of it, right? I think I lost some of that excitement probably because I became more inhibited as I…you know, puberty and all that business with adolescence. I became more inhibited and was much more interested in trying to be cool and so was much more focused on sports and girls and music and things like that and was much less interested in things that would label me as a science nerd. So I sort of pushed all that stuff away. (DC)

Some scientists recalled the low expectations of their community as a pervasive obstacle. In other words, the degree to which a local population reveres science is at least partly a function of the existence of a significant science and technology workforce. That, in turn, is a reflection of the presence of science and technology related jobs or a major university or research center. The distinction is more graphic when moving from one location to another, as the next quote reveals:

> The students in the area where I grew up were probably much more focused and motivated, if only through peer pressure, and the expectation that you went to college was just always there. For most kids that I grew up with it wasn't even a fact that you might not, whereas around here it's very different. You can certainly see the difference in the expectations and what students see for their future, which include the trades much more than professions or career paths. (GR)

Similar to this, but significantly more localized within the school, is the negative peer pressure foisted upon some by certain factions, some of which were well defined (e.g., “jocks”) and some which were more nebulous, as these next two accounts illustrate. In the first account, since the scientist did “fit in” by virtue of being an athlete, the peer pressure was not too oppressive. The second account is most poignant in that it lays bare the debilitating nature of peer pressure at its extreme:

> My recollection is that most people considered it [taking challenging courses] “geekish” other than the people who might have had nursing or medicine or a prospective career in mind. I think most people considered anything other than what the “brains” studied… My friends certainly gave me a hard time, but I think probably a lot of the courses I took they didn’t take—you know, some of the higher math, taking a full spectrum of the science curriculum such as it was at that time… They didn’t harass me – just kind of gave me good-natured ribbing. Physics is the one class I remember – physics and chemistry – I probably had more of my friends who took those classes. But I think also because I played sports, I had a lot of friends who were just basically jocks, and they were not going to take physics or chemistry because it was too hard. They had a tough-enough time taking the general math requirements. (FR)
>
> The obstacles were really my peers. It was really hard. When you are fifteen and your peers are going to the movies or playing ball and they ask you, “Why aren’t you doing anything tonight?” “Because I have to go and read something.” I was an outcast, and that really hurt. And they would [think], ‘Well’ he’s an outcast. He’s not one of us.” I really felt alone and I was thinking why should I do this? I mean, I’m not a genius. Am I living a fantasy? Why am I doing this? It was hard. Ninth grade was the hardest year. That

> was when I just wanted to belong. I just wanted to walk away from everything because it was just too tiring to be alone. (WR)

One of the ways in which some schools attempt to deal with negative peer pressure is to try to partition it by requiring everyone to wear uniforms or separating the boys from the girls. Though this has certainly met with a modicum of success, it sometimes backfires, as the following scientist recalls:

> I went to an all boys high school and I think the purpose of that was to hopefully eliminate some of the peer pressure associated with girls but for me it kind of maximized the peer pressure. I was comfortable talking to girls, more or less, at least on a friendship level. Guys that were my peers, I felt like I had to impress them, and I had to fit in and I had to play sports and listen to the right music and all that business. So that was probably more of a struggle for me than it would have been in a coed [school]. (DC)

An effective antidote to peer pressure is a strong and supportive family, the same powerful influence that has been frequently cited in numerous other contexts. This point was not lost on the following scientist, and are all the more convincing because of his Hispanic heritage:

> I certainly see that there is a cultural bias that can influence whether the kids are influenced in science – and, certainly, if I'd paid attention to my friends when I was in high school, I might have responded to peer pressure and avoided science, but the pressure from my dad was a lot stronger than any that I might have experienced from my peers. So the familial support for something like that is probably very important. (FR)

Many of the scientists commented on the tremendous value of positive peer pressure. Sometimes this involved a single individual who was in the right place at the right time. Most of the time, however, it took the form of a cadre of colleagues who mutually encouraged and exhorted each other. Besides enabling them to endure the sometimes withering negative peer pressure or the desire to give up, these groups were both educational (in that they fostered collaboration) as well as social, resulting in lasting friendships. In this respect they are not unlike the cohorts often formed by alumni as they pursue their advanced degrees.

Another benefit, as the next recollection will reveal, is the kind of healthy competition that prods the members towards increased excellence, even more than parents and teachers are sometimes able to do:

> We had fun but I also had a really good group of friends. I think that made a really big difference. That was the most competitive and yet supportive group of people I have ever been around so we really pushed each other and we got more out of it because of that… I had the same group of friends since second grade… Then we melded with another school that had a similar situation where they had been friends since forever. And our parents were all very active in our lives. So I think it was mostly us, more so than any individual teacher, although I think some of the earlier teachers had a big influence on my life even back in grade school but by the time I got to high school it was really I think more us than the teachers. Not that they didn't play an important role too. (DN)

One advantage of positive peer pressure that is often overlooked is that it creates a classroom environment in which it is a joy to teach. The discipline problems are minimal (as seen in the next quote) and the enthusiasm is high:

> There was a guy that I studied with all the way through high school because we were in every class together because we both were interested in science and you have this small core group that went through all of the same classes. And when you have a group that is

> interested because they wanted to be, management of the class was not difficult. So that never seemed to be an issue that I can recall. (MH)

In the end, a cycle of positive reinforcement is created – the energy of the students and teacher fuels each other. The teacher is now able to move from a more “front and center” role involving discipline and coercion to one of support and guidance. This is especially critical when the family and peers are non-supportive:

> There were four of us… some people would call us nerds. We didn’t think we were nerds. We were into girls and sports just like any of the other guys in school. We loved the sciences. We would sit around and we would do exercises, talk to each other about what we wanted to do when we grew up. I think we really got the support that was really missing in the rest of school, and in our homes. (WR)

Influence of Career Counseling

For most students, if they receive any formal career counseling at all (outside of their family), it is from their high school guidance counselor. Most counselors spend their time helping students (1) understand and cope with family members and friends, (2) deal with issues of behavior, discipline, and school work, (3) plan next semester’s course load, and (4) prepare for and enter college or the workforce after high school. Depending on the resources of a school and its community, there may be a counselor who helps students recognize their own gifts and talents, instills in them a vision to pursue their dreams, and guides them so that they are prepared to reach the next level in that pursuit.

This is a tall order, and one that is increasingly important as more and more students have no place else to turn. It can also be a deterrent if the counselor is not knowledgeable about the requirements necessary to progress in a given course of study, such as science. (This point will be revisited later in this paper when nine women scientists report via an online oral archive that their high school guidance counselor specifically discouraged them from seeking an advanced degree in science.)

As the literature has shown, success in science in college is predicated greatly upon the rigor of the science and math courses taken in high school. When this fact alone is considered, a counselor, who strongly encourages students with an aptitude and interest in science to take all the necessary prerequisites possible, can be extremely influential. The counselor, of course, is only one of the ingredients, and sometimes just plants the seed, as the following scientist admits:

> It was a high school counselor who suggested to me in my junior year that I take physics in my senior year. Her suggestion was based on my high grades in math and a brief conversation we had. I would not have ever considered physics in high school on my own. My real academic interest in physics (geophysics actually) began when I was working for an oil company at the age of 22. I may have been receptive to this based on my high school physics experience and a positive junior college physics class. (TR)

Some students have a vision early on for what they want to pursue and take the necessary steps to realize it. For such a student, all the guidance counselor needs to do is make sure that all the courses are taken at the right time and in the right order. Their role is not one of initiating a plan, but facilitating it. The following assertion illustrates this point (and also shows the much greater impact of growing up in a family with high expectations):

> It was always an assumption [to go into science in college]. I think probably by tenth grade, I had my four year college curriculum worked about, so that I took the right classes in high school to do that. So, that was just a given. It was time to work out what

> you would take in college so that you don't miss anything in your last few years of high school. I just think that I made that assumption early and just stayed on that track. (MH)

Other students, however, figure out their plans as they go along. Some of these students may follow a more or less direct path, as did the scientist who is quoted next. But how many students are lost to science because a critical piece of guidance or encouragement was not forthcoming at an opportune time? Skipping a science class or giving up in a math class could make all the difference:

> Well, I think what I saw in my high school curriculum was enough to tell that there was a need for people who could think reasonably about these sorts of subjects and the teaching that I had was pretty encouraging along the way. Nothing was really explicitly painted for me as far as saying "You could make a living of this," or "There are a lot of areas where you could look forward." That was something that I could figure out myself… So to what extent did my high school experience influence my decision to go into science? It did, but in those days career counseling was not as explicit or up front as it is today. (GG2)

Influence of Math Preparation

One of the gatekeepers for entrance into science and engineering careers is math competence, as the literature has shown (George, et al., 2001; O'Brien, et al., 1999; Rohrer & Welsch, 1998, Trusty, 2002). This point was a tacit assumption by most of the scientists and was frequently alluded to in almost a matter-of-fact way. Some scientists recognized that math is intrinsic to doing science, especially the physical sciences like physics and chemistry, because of the problem solving skills it fosters. For example:

> I think that, if you want to take physics and your math is bad, it will just be really, really difficult. And so I think that they typically go hand-in-hand. But I definitely think that, if

> you don't have the math, it's going to be difficult because [math is] the basis for a lot of the problems and the thinking and all that. Maybe some things aren't as math based, although I think that even biological science tend to do those types of things. (JI)

For some of the scientists who were interviewed, this competence was a result of innate ability and thus only tangentially affected by math teachers. One ramification was that poor instruction did not dissuade them from going into science but did affect which science they pursued. This seemed to be more common in choosing a career in the biological sciences over one in the physical sciences. In both of the following musings, the selection of a future major, at least in part, was due to disenchantment with math, either because the math teacher was not liked or the math teacher was not exciting. The extent to which a "dislike" for math resulted in a dislike of the teacher or the course is moot:

> Maybe that was what really shaped me as far as going more towards the biological sciences while I had a lot of chemistry and physics… I don't know if it was necessarily maybe I didn't like chemistry and physics so much in high school because I didn't necessarily like the teacher as well as I liked [the biology teacher]. Maybe that goes back to not being all that fond of math anyway. I think physics and chemistry have to use a lot more math. (BL)

> In retrospect I think I wish that my physics teacher, who also taught math (because a lot of the math that I took was from him), had been a little more exciting because I distinctly recall going to college with very little interest in taking more math and very little interest in taking physics. I did those things in college because I had to for my degree. But I took the minimum amount necessary and fortunately my field of study in biochemistry didn't really require a lot of advanced math. I took physical chemistry – it was one of the

> requirements for the degree and it was very hard for me because I didn't have differential calculus that I needed. (FR)

Another result of poor teaching was that it took additional work in college to compensate for it. As one scientist remembered about her math teacher who was also a coach, "He was a great guy, but I think of my math [in high school] and math in college and a lot of it was like 'No, coach didn't do a good job on this,' so I had to play catch up there" (JB). However, sometimes the additional effort necessary to overcome a poor background in math can be monumental so that the plans for a career in science are dropped.

As has already been shown in other contexts, the kind of learner a student is and the kind of style the teacher has may or may not jibe. The following two recollections demonstrate the far-reaching implications of this:

> Science is tightly tied to mathematics so the setback I think I had in math was influential on what I did and what I chose to do. I had a math teacher in junior high school whose motto I remember was, "Don't understand it, just do it." I think his intent was good – that at some point you just have to memorize things, you don't always have to rely on understanding. [But] when I asked questions, I could understand something better. But that [rote memorization] just wasn't helpful. I didn't do well in that math class… but I think that turned me off to math. I felt not only that I wasn't good at it, but it was just memorization, at things I wasn't good at memorizing. (MP)
>
> I think it was my personality type. I tend to prefer objective things over subjective things, so classes like philosophy and social sciences I really struggled with. More quantifiable things I tend to be able to wrap my brain around a little better. I was real strong at math in school. I don't use it as much now. I do stats and apply stats, but I

> don't use math to the extent that a physicist or an engineer uses it so I lost a lot of that edge. (DC)

On the positive side, a strong math foundation can lead to a valuable skill in and of itself. As one scientist declares, "It was largely…through math that I developed an interest in programming…" (TR) and that, in turn, became an important part of his job. It can also (1) expose the student who is undecided as to a science career and open it up as a possibility of a career and (2) make the transition into college level science courses less of a barrier. One scientist describes how both of these benefited her:

> I took four years of math in high school through the most advanced math class… In doing the math a lot of the particular word problems and stuff had sort of a science bent or an engineering type of bent and so you got a little bit of a taste of doing, of working calculations and stuff that might be related to it. And so I thought that that might be a neat thing to do past high school and I liked that… Another thing, as we were talking about before, I think is important is that in the sciences, if your math is weak it makes it very difficult to continue to pursue that. So I think that, if nothing else, it was pretty much what allowed me to be able to go into science once I got to college… But then the advanced class at our high school taught pre-calculus – that kind of stuff, a lot more detailed stuff. So I was able to move right into a calculus class in college, and I think that if you're not doing that, it would be very difficult if you decided that you wanted to go into the sciences. (JI)

Women and Minorities in Science

None of the women scientists who were interviewed recalled experiencing any kind of gender prejudice while taking science classes or participating in science related activities up through high school. Yet, maybe there was more of a silent bias of omission rather than an overt bias of commission. In other words, maybe the girls were not informed about careers in science or encouraged to pursue them to the same degree that boys were. As the following scientist again notes, it is all about teachers, both in terms of their personal interactions with the students and their management of the classroom discourse and experience:

> I did think about that, and I thought it was significant that I never had that feeling [of discrimination]. I might have had more in college, and somewhat in graduate school, but I remember being surprised when I was in college seeing a poster saying encouraging women and girls to think about being engineers. But I really didn't encounter that at all [in junior high and high school]. Thinking about it, I've just been really lucky to have great teachers, and I think that makes a real difference. (AW)

In a later section of this analysis, other women scientists, responding to questions on an online oral archive, recount numerous egregious examples of gender prejudice while growing up. Most of these had to do with job stereotypes and reduced expectations, often on the part of guidance counselors. But one interviewed scientist did relate several experiences after high school in which the gender bias was an obstacle in one instance and instrumental (for a job) in another. In both cases, the scientist was eminently qualified in her own right:

> Well, I did have interviews like that, that were pretty "iffy" legal things. I actually was asked questions like, "Are you on the pill and are you married?" Things that, of course now, would provoke lawsuits. One reason I probably went to graduate school was because I had difficulty getting hired with a B.S. degree in physics, and I think that part of that was due to being female. And when I got out of Ph.D. school, it was just the opposite because of these quota systems. And it was almost like trophy hunting. I got

> here because someone chased me through the lobby of a conference, saying, “The next person we hire has to be a woman, and you’re even sort of qualified to do what we want.” And I’ve talked to other women of my generation who had kind of the same experience. Sort of on the cusp of when you couldn’t really get hired in advance and then when companies were strongly encouraged to hire women. (JP)

Scientists who are minorities (or came from poor families, or both) no doubt also encountered the similar prejudices of stereotyping and lower expectations. But an additional hurdle is often the economic one – minimal opportunities to experience science and limited access to the ones that are available. In school this takes the form of dilapidated labs or limited materials from chemicals to computers. More problematic is the likelihood of classroom teachers who are poorly trained, underpaid, unable to attend conferences and workshops because of the lack of funding, or so burdened by dealing with the serious social issues routinely confronting their students (broken homes, violence, poverty) that little time is left to actually teach science.

One scientist hints at a difficult dilemma (the proverbial “Catch-22”) in the next quote. On the one hand, if the teacher works hard at implementing the curriculum and providing a solid foundation in science, then he/she may not have the time to do those things that enable the students to experience and enjoy science, like demonstrations and lab activities. If, on the other hand, the teacher commits to getting the students excited about science (and actually has the resources), then he/she may not have the time to cover the curriculum. He observes:

> You see these really astoundingly sharp kids, and a primary barrier to their going on to college and being successful scientists is really economic. But, if you get kids, say, at the high school level [who] don’t get engaged in science and this is uniform, not that there’s

> no cultural bias that I can see. But it's uniformly [true that] a lot of schools have very little time or resources in the kindergarten through junior high levels to do much enrichment in the sciences. And so giving kids the idea that science is a viable career to aspire to or that it might even be fun is not something that teachers have the time or energy to do. There have been some notable exceptions but, by and large, notice that the teachers who become too busy to do much else than teach the curriculum, become increasingly focused on standardized testing. (FR)

One thing that is true regardless of socioeconomic status (SES) is the essentiality of encouragement. However, in a low SES environment, the encouragement is even more crucial, and must come from more sources (especially if there is only one parent, working two jobs to make ends meet), and must be more than heartfelt words. Consider the following reflection of a scientist who grew up without a father:

> The encouragement was phenomenal from everybody in my neighborhood, people in the church. I was very active in the church and they knew I loved science. And when I was in the ninth grade I really felt the need to escape from Memphis. And that is when I actually was taking a couple of tests and was introduced to a couple in Memphis, a Jewish couple, who really just embraced me and they wanted to see me go on. And they actually provided me with some of the financial resources and they financed the trip to Exeter [a private, prep high school in Massachusetts], and money for books. And they talked to me about escaping and really living my dream. Lots of people stepped up. (WR)

One scientist, who is both a woman and a minority, comments on the encouragement she received at home and the encouragement she received through a special program. An important point is that it is not the program, per se, that necessarily makes the difference, but the people within the program and the participant's relationship with them that is influential. She recalls:

> As far as special encouragements, I have always had that from my family (I have two older siblings not in the science field) but they as well as my parents were very supportive toward my younger sister and me. I was especially encouraged when I participated in a minority program at the private university/medical school that was focused on preparing minorities for entry into medical school. I was already working in the science field and realized that although it would be nice to be a medical doctor, being a scientist was still quite rewarding. The head of that minority program was a researcher himself and had a Ph.D. He was a minority and on the board at this medical school. He was a very impressive man and was quite encouraging. After meeting him, I thought I did not have to be a medical doctor to make a difference in peoples' lives, being a scientist has that reward as well. (EP2)

As important as encouragement is, it should never be doled out in a patronizing way. Certainly, if the minority student has an equal opportunity to gain a quality high school education and to pursue a career in science, then no more encouragement is needed for him/her than is needed for anyone else. The next scientist makes this very clear:

> I didn't consider myself as unintelligent, so I didn't need the encouragement. I knew what I liked and that I had self-motivation to pursue what I liked. But it's just like with anything. Anything that you don't understand you kind of discourage and I didn't see anything as tough or a challenge. What was so tough about it? So I think if you're in a situation where you're not sure what you want to do, you need that encouragement and that could play a big

> role why African Americans aren't into sciences. It's intimidating. I didn't see a lot of African Americans in classes. (RB)

Even though this program was not part of her high school experience but occurred much later in her career, the following recollection by the previous scientist (EP2) corroborates the observation made earlier in this section that, at least for two of these scientists, any prejudice encountered *within the academic arena* was more blatant during their post-secondary education:

> Well, believe it or not, it really was not until I came to the United States that I realized that I was a minority, so that was a learning experience for me in itself. I did not find any physical obstacles per se but I did realize that minorities seem to have to work a little harder to get the same goal as others. I don't remember anything in particular that discouraged me from wanting to pursue science. However, I do remember when in college some of my friends had a chemistry teacher who was somewhat prejudiced and thought minorities (in this case they were black and from Haiti) were not fit for the science field. That was a little disappointing to hear and it made me wonder if others in the field would think that of me. I did not let it stop me from obtaining my chemistry degree but I did wonder if people I would work with would feel the way this professor did. Once I reached the working environment in the capacity of a chemist, I found that not to be the case. My supervisor and manager were really impressed with my laboratory skills and that made me feel very comfortable in this field. (EP2)

Encouragement, and the aptitude and self confidence that results from a solid preparation by excellent teachers, can overcome a multitude of social ills.

Because the women and minority populations represent a valuable source of scientists, their under-representation in the sciences is a topic worthy of intensive scrutiny. Though it is beyond the purview of this study to investigate this issue further, one important point bears mentioning: At the very least, the factors that positively influenced scientists to pursue and persist in science careers while they were in high school, can benefit everyone, regardless of race, gender, or socioeconomic background.

As has been shown, all of the influences predicted by the literature review were not only paralleled in the interviews, but greatly amplified and enriched. This was particularly true in the discussions of teachers and their pedagogical practices. Before these findings are summarized, however, they will be compared (triangulated) against the autobiographical accounts presented in the next chapter.

CHAPTER 5

Findings: What the Autobiographies Say

Introduction

As was discussed at the end of the review of the literature, only two studies actually polled scientists about their *own* opinions and experiences regarding science education. Of these, one was the questionnaire by Lawton (1998) sponsored by Bayer Corporation of 1,435 Ph.D. holders who were members of AAAS (American Association for the Advancement of Science). This casual inquiry merely asked for opinions regarding the propriety of various high school pedagogical practices. Nothing about the scientists' personal experiences or what particularly influenced them was forthcoming.

The other study was a survey by Rowsey (1997) of 35 research scientists. It had two limitations, as far as the purpose of this dissertation is concerned. First, a survey is certainly more open-ended than a questionnaire, but it is neither as personal nor expansive as an interview. Second, the survey had only five items, and these were not particularly about high school experiences but about their formal and informal education in general.

Some of these same shortcomings (in terms of this dissertation's research questions, not in terms of the scientists' own research goals) are apparent in the following biographical sketches. Nevertheless, numerous observations by the biographers about their subjects and personal comments by some of the scientists themselves are extremely apropos. Not only do they provide broader color and texture to the narratives of the scientists interviewed for this study, but they also corroborate and triangulate those accounts as well. Finally, it should be noted that the materials identified for review in this chapter are for the most part either *autobiographical* (i.e., the online oral archive), or taken from sources where scientists were directly interviewed. Thus they more precisely mirror the primary source material (interviews) analyzed in Chapter Four.

Organization

With this in mind, this chapter will begin by looking at the accounts recorded by Roe in *The Making of a Scientist* (1952), arguably the first study of its kind on this subject. Only those remarks concerning pre-college experiences will be relayed. The second section will summarize the results of several sources of autobiographical (and some biographical) information about Nobel laureates and other world-renowned scientists. Lastly, an active database, generated by a web site onto which women scientists may log in in order to answer prescribed questions, will be perused.

The Making of a Scientist

An overview of Roe's study and the significant differences between her investigation and this one were set forth at the beginning of Chapter Four. Many of the questions to which she sought answers are emphatically suited to uncovering the reasons someone might pursue science as a career, but are outside the scope of the narrower confines (high school-related) of this research. For example, she tabulates the birthplaces of the scientists she has selected, their family position (e.g., first-born), their average age at receiving college degrees, their age when they lost a parent, and their scores on verbal, spatial, and mathematical tests.

Some of Roe's questions parallel those asked during the interviews conducted for this research. For example, half of the scientists Roe interviewed had fathers who were professional men, often scientists and engineers themselves. A high value was placed on learning for its own sake. Also, "most of them were inveterate readers, and most of them enjoyed school and studying" (p. 231). When the parents were not responsible for creating this climate, then someone else was – usually a teacher.

Somewhat stereotypically, Roe observes that the physical scientists almost exclusively "were early involved in gadgeteering of one sort or another" (p. 232), and the biologists "were extremely interested in natural history from early childhood" (p. 232). Parenthetically, several other stereotypes having to do with gender differences and scientist/nonscientist differences were proffered that would no doubt be highly criticized today.

Because several of the other referenced texts containing biographies talk about curiosity, even to the point that it is part of their titles, the fact that Roe also talks about it is relevant:

> One of the first things one notes about scientists is the fact that a large part of their time is spent in thinking about things, in a question-answering way. They want to find out something, and all of their activities are designed to bring them answers to questions. (p. 234)

Another trait that is also emphasized in other sources is that scientists are "driven" (p. 238). This characteristic will be unpacked later in this section.

Roe does comment on the role of the science classroom when the curious student is driven to find answers. Referring to her interviews, she summarizes:

> There are other implications for educational practice in these stories. The discovery that it is possible to find things out for oneself is not a natural part of growing up for every child in our culture. It can be seen clearly in these life histories that for many of these men it was just chance – the chance, usually, of getting in a class in school where this type of activity was encouraged. Whether it was encouraged because the teacher was genuinely interested in encouraging the children to think for themselves, or whether it was

> encouraged because the teacher did not want to be bothered with the students and so left them pretty much on their own does not seem to matter too much. The important thing is that they learned that they could satisfy their curiosity by their own efforts. Once they did learn this, good teaching encouraged them, but bad teaching did not stultify them. (pp. 238-239)

In bringing this subsection to a close, two of the scientists – a biologist and a physicist – that Roe interviewed each describes his teacher. Note that the theme of semi-independent discovery is common to both:

> In high school I was interested in physics and chemistry. I suppose the biggest influence in high school was a particular teacher who taught physics and chemistry. I guess she didn't know too much but she was a very good teacher, allowing people to go ahead and express an interest. She used to let us work after hours in the lab and fool around and it's a wonder we didn't blow things up. She thought I should go to college. (p. 101)
>
> The first few years in high school I don't remember anything special about… I took physics and didn't like it. I had taken chemistry before I got there, but there was an extra course that sounded interesting so I took it and it turned out there were only four students in the course and a very interesting teacher. He sort of took personal charge and let us do pretty much what we wanted except that he was extremely insistent that we take care and do a good job… I think that teacher had more individual influence on me than any other. (p. 108)

Nobel Laureates and Other Eminent Scientists

The methods and processes of science that we practice today (simplistically called, sometimes, the "scientific method") first took root during the Reformation in the 16th century, when the absolute authority of the established Church was challenged in the arena of "natural revelation" (Nature) concomitantly with a challenge in the arena of "special revelation" (Bible). During the five centuries since there have been many great scientists, with the attendant biographies detailing their lives. This section will only look at those who lived most, if not all, of their lives since the beginning of the 20th century. In addition, in order to make the task manageable and because only a glimpse of their formative years is desired as opposed to an exhaustive discourse about their lives, just three comparative anthologies instead of a spate of biographies will be assessed.

Weber (1980) surveys 111 *Pioneers of Science* from 1901, when the Nobel Prizes in Science were first awarded, to 1979. Of these biographical sketches, 53 contain information relevant to this study. All but one (Marie Goeppert-Mayer) are men. Merged with this list are seven of the nine women recipients (out of a total of 309 awarded through 1993) and Lise Meitner as reported by McGrayne (1993) in her book *Nobel Prize Women in Science.*

The biographers spend very little time probing high school science-related experiences (hence the need for this dissertation) but they do comment frequently on other factors during their adolescence that no doubt contributed to their pursuit of a science career. (These have already been identified in this chapter.) The list, found in Appendix D, is chronological by the year (in parentheses) in which they won the Nobel Prize.

Ten more recent Nobel recipients – eight men and two women (including repeat Gertrude Elion) – were interviewed for a United States Government manuscript entitled *Curiosity is the Key to Discovery: The Story of How Nobel Laureates Entered the World of Science* (1992). Their high school science-related experiences conclude this subsection of "What the Biographies Say." Again, note that there are numerous references to experiences and situations that on the surface appear to have little to do with high school, per se. However, they were included because they resonate with many of the recollections recorded both in the interviews as well as in the biographies.

The first scientist who contributed to this publication was Gertrude Elion (Medicine, 1988), who relates a bittersweet experience that influenced her entrance into science when she was a senior in high school:

> It was about this time that my mother's father who lived with us had cancer. My grandfather and I were very close – I was the apple of his eye. He was taken to the hospital and, after a while, I was allowed to visit him. Seeing him there, I remember how shocked I was at his change in appearance. It was the first time I really understood how awful disease could be. I wondered how this happened to people. In the hope that could do something to combat disease, I decided to become a scientist. (U.S. Department of Health and Human Services, 1992, p. 3)

Rosalind Yallow (Medicine, 1977) was encouraged to become an elementary school teacher by her family. But "by the seventh grade I was committed to mathematics. A great high school teacher excited my interest in chemistry." (p. 4). She was also tremendously influenced by Eve Curie's biography of her mother, Marie Curie.

Claiming that "persistence and commitment are the name of the game in the field" (p. 5), Leon M. Lederman (Physics, 1988) demonstrated this persistence when:

> I was eleven or so, I got the measles. To help pass time while I recovered, my father bought me a book, *The Meaning of Reality b*y Einstein and Enfield. It's a wonderful book which starts off like a detective story, talking about how detectives seek clues to solve a puzzle. That book got me interested in science. In high school, I was a B- to B+ student,

> far below the class leaders, but I did have a passion for science. (U.S. Department of Health and Human Services, 1992, p. 5)

Julius Axelrod (Medicine, 1970) agrees with Lederman about the grades:

> Don't be so sure that you have to achieve terrific grades in school to be accomplished in science. At age 14, I really wanted to go to Stuyvesant, the high school for bright students, but my grades weren't good enough. My real education was obtained from the Hamilton Fish Park Library, a block from my home. I was a voracious reader and read through several books a week. (U.S. Department of Health and Human Services, 1992, p. 6)

It wasn't until high school that Glenn Seaborg (Chemistry, 1951), whom this author met several years before he died, took his first science class:

> Up until the time I entered high school, I had no exposure to science and, therefore, little knowledge of its possibilities… Largely due to the enthusiasm and obvious love of the subject displayed by my teacher, Dwight Logan Reid of David Starr Jordan high school in Los Angeles, chemistry captured my imagination almost immediately. (p. 7)

Like Axelrod, he affirms that hard work is an essential characteristic of a scientist, and like both Axelrod and Lederman, he confirms that "You don't have to be a genius to become a scientist… We cannot hope to carry them [necessary tasks] out without help from people of many levels of ability" (p. 6).

Francis Crick (Medicine, 1962) did not seriously pursue a scientific career until he was 31. However, his avid reading paved the way, beginning years earlier when he was given a children's encyclopedia. The manuscript relates that:

> The books captured his interest and he answered his own questions by conducting experiments at home. Once he attempted to make artificial silk. In another experiment he blew up bottles using electricity, which didn't go over too well with his parents. Francis was a fine student who says he didn't care much for math and chemistry but was interested in studying physics. He also loved to play tennis, soccer and rugby. (U.S. Department of Health and Human Services, 1992, pp. 8-9)

By contrast, Joseph E. Murray (Medicine, 1990) became interested in science as a small boy:

> From earliest memory I wanted to be a surgeon, possibly influenced by the qualities of our family doctor who cared for our childhood ailments. As a second year high school chemistry student, I still have a vivid memory of my excitement when I first saw a chart of the periodic table of elements. The order in the universe seemed miraculous, and I wanted to study and learn as much as possible about the natural sciences. (U.S. Department of Health and Human Services, 1992, p. 11)

Many scientists also have a passion – and frequently a proclivity – for music. J. Michael Bishop (Medicine, 1989) was torn between the two, but after participating in both in school, he realized that he was more proficient in science. Also, like many scientists, he became interested in his field by reading about it on his own (p. 12).

Like some of the scientists who were interviewed, E. Donnall Thomas (Medicine, 1990) graduated from a small, rural high school. But as a boy, he was already called "Doc" because he would assist his father, a country doctor, on minor surgeries and other treatments while he made his rounds. Thomas avers, "Scientific careers involve a commitment to hard work, continuing study throughout one's lifetime, a keen curiosity to explore unproven theories and patience to stick to the job despite setbacks" (U.S. Department of Health and Human Services, 1992, p. 10).

Several very diverse experiences drew Marshall Nirenberg (Medicine, 1968) to science well before he entered college:

> In 1941, when I was eleven, I developed rheumatic fever and to protect my health we moved from New York to Orlando, Florida, then a small town. To me, Florida was a natural paradise in those days. And I was the kind of kid who was happy exploring swamps and caves, and collecting spiders. I once waded in water up to my waist for a half mile in order to view a rookery where thousands of pelicans were nesting on low mangrove bushes. An unbelievable sight! (U.S. Department of Health and Human Services, 1992, p. 13)

The last scientist cited in this source was David H. Hubel (Medicine, 1981). His pre-college experiences reveal a weaning process of sorts, as he pursued one science and then another. He eventually settled upon both chemistry and electronics:

> He credits his parents for encouraging his interest in science and patiently answering all of his questions on the subject when he was a boy. After constructing several malfunctioning electronic experiments, Hubel devoted more of his attention to chemistry. He discovered that combustible mixtures or the successful launch of a hydrogen balloon were more exciting and less frustrating. (U.S. Department of Health and Human Services, 1992, p. 14)

In his on-line autobiography, Frederick Reines (Physics, 1995) reveals his interest in building things, music and singing, and books, the latter due to the professional studies of his three older siblings. He admits:

> The first stirrings of interest in science that I remember occurred during a moment of boredom at religious school, when, looking out of the window at twilight through a hand curled to simulate a telescope, I noticed something peculiar about the light; it was the phenomenon of diffraction. That began for me a fascination with light. (Reines, p. 1).

Boy Scouts contributed greatly to his interest in science because, as a part earning badges, he began to build rudimentary ("crystal") radios. But he was "strongly encouraged by a science teacher who took an interest in me and presented me with a key to the laboratory to allow me to work whenever I wanted" (p. 1). His personal yearbook entry claimed that his principal ambition was "To be a physicist extraordinaire" (p. 1).

By contrast, Tony Leggett (Physics, 2003) entered science as an afterthought.

> Almost out of the blue I decided to go into physics. My father had been a high school physics teacher, but he never really tried to interest me in it. I went along to one of his courses once but found it completely incomprehensible. (Sample, p. 1)

Evidently his lack of knowledge or background did not deter him because be finished his undergraduate degree a year early before going on to Oxford.

In summary, 45 of these 71 laureates had at least one parent who was a scientist, loosely defined here to include engineers, professors, and active encouragers of science. (Four of these winners had parents who were themselves laureates!) Extended family members such as grandfathers and uncles were also influential. Six schoolteachers were recognized, along with the tutors and parents who were involved in their formal instruction and encouragement.

Non-traditional schooling figured prominently. Six of the laureates had tutors, five were home-schooled, and eleven attended private schools at least during some part of their high school years. These private institutions included special schools with a science emphasis, such as the

Bronx Technical High School and the Stuyvesant School for the Gifted. In addition, ten of the laureates had parents who were college and university professors, and seven had parents who either taught high school or wrote texts for high school.

Reading was so important that more than a dozen of the laureates made special mention of it. Five laureates highlighted math. Growing up on a farm or ranch, working with tools, or repairing machinery were early equivalents, perhaps, of “hands-on” experiences and were mentioned half a dozen times. Childhood “toys” were usually provided by parents and included microscopes, lenses and magnifying glasses, chemicals and crystals, lab equipment, and electronic equipment.

A number of the laureates fondly recalled the scintillating discussions that they had with their parents about both scientific and non-scientific matters and visiting professionals in their places of work. Other rich and influential times (often with a parent) included trips to a laboratory, working together to build an observatory, taking and developing color pictures, going for walks, fossil hunting, studying plants, looking at the stars, doing chemistry experiments, constructing electronic devices like crystal radios, assisting a parent with his work, and launching hot air balloons.

Many of the laureates showed a strong scientific proclivity early on in their lives, often graduating early from high school or publishing scientific treatises before entering college. However, not all of them did well academically in high school, some of them never had a science course until high school, and some did not even chose to pursue a career in science until well after college. On occasion, it was an unplanned experience – watching a grandfather die or developing a disease – that proved to be a turning point.

Curious Minds

The next sources of information in this subsection are autobiographical accounts by some renowned scientists selected by John Brockman (2004) for his book *Curious Minds: How a Child Becomes a Scientist*. In a sense, it, too, is a half-century follow up of Roe's study but has a completely different format in that each scientist is granted a chapter to tell his/her own story. As a result, the dialogs are substantially more vibrant and frequently lapse into eloquent discourses on the philosophy of science, the nature of learning, and the challenges facing culture and society. Four of the 27 scientists are women, and a number of the researchers practice in the sociological sciences (e.g., psychology), a subset not included in this dissertation's focus.

Twenty-one of the scientists referred to their parents (or occasionally another member of the family or a family friend) as instrumental in their entrance into science. Half made mention of their parents' scientific degrees while most of the others, while not naming their parents' professions, spoke descriptively of their active involvement in scientific pursuits and hobbies. Fourteen scientists went out of their way to emphasize the importance of books while four referred to television programs, no doubt due in part to the fact that these accounts are recent and the scientists somewhat younger than most of the aforementioned Nobel laureates.

The descriptions and quotes that follow were chosen because they both augment and corroborate the life stories that have already been portrayed thus far in this chapter. Each of the following twenty-three scientists therefore adds his/her own perspective and color to the tapestry of influences and experiences through high school that propelled them, consciously at the time or not, towards their present scientific endeavors. (Unfortunately – but characteristic of most of the extant biographical accounts – these eminent researchers were not directly asked to address their early education.)

The first scientist in Brockman's book is Nicholas Humphrey, a professor at the London School of Economics and professor of psychology at the New School for Social Research. He is a theoretical psychologist and is internationally known for his work on the evolution of human intelligence and consciousness. There is no question that he enjoyed a scientifically rich and privileged childhood. Speaking almost reverently of his grandfather A.V. Hill, a Nobel Prize winner himself, he surmises, "He could have done the experiment alone. But science for my grandfather was nothing if not a family affair, and he had long been in the habit of engaging his children and grandchildren as his assistants" (p. 4).

Even before he spent six months at the age 17 at the Marine Biological Laboratory at Plymouth as a lab assistant, he remembers:

> As children, we lived and breathed science, though of course we didn't know this at the time. Our sprawling basement rooms were full of apparatus: prototype engines of my grandfather's, pumps and torpedoes, lathes and jigsaws, Meccano [erector] sets, photographic apparatus, Wimshurst electrical machines, microscopes, aquariums. We spent Saturdays running around the corridors of my father's institute. We went on outings to my uncle Maurice's observatory in Cambridge. We went on trips on the research ships out of the Marine biology Laboratory. We accompanied Stephen's family on expeditions in search of flint arrowheads in the woods at South Mimms. (p. 10)

From the "sublime" of Humphrey's ideal adolescence, to the "ridiculous" of a popular TV show, Robert M. Sapolsky, professor of biological sciences at Stanford and of neurology at Stanford's School of Medicine, recalls "Gilligan's Island" and the professor who:

> Has every book ever written somewhere in the trunk he was marooned with; he can answer any challenging question you can think of; he is forever saving everyone by

> rigging up some sort of scientific device. The professor can do anything (except get them off the island, of course). (p. 19)

From this rather innocuous beginning, Sapolsky transitions to more sophisticated ruminations made possible by his father's occupation:

> When I was eight or so, I decided I wanted to study apes in the wild. It really wasn't a particularly coherent, cognitively shaped interest, just an outgrowth of the earlier dinosaur stage. I had started with the dinosaurs, but my father was an architectural historian who had done some archaeology in this time, and that got me to the King Tut's tomb stage. From there, I progressed to the bones of our hominid ancestors. But at some point I started going to the Bronx Zoo and the American Museum of Natural History, and the primate exhibits simply did something to me that the bones and potsherds couldn't approach. (p. 20)

For Mihaly Csikszentmihalyi, Professor of Management at the Claremont Graduate University in Claremont, California, passage into science was more happenstance, having traversed his childhood more or less scientifically unscathed:

> When I was about 17 years old, …I heard Carl Jung give a talk on flying saucers. This was during a skiing holiday in Switzerland that turned out to be too late in the season, since the snow on most of the slopes had melted. There was a simple reason for attending the lecture: I didn't have enough money to go to the movies and the lecture was free. I certainly didn't know anything about Jung and had only a vague notion about psychology. But flying saucers sounded interesting. (p. 31)

It was not extra-terrestrials but the brother and the father of Murray Gell-Mann that propelled the current Professor of Theoretical Physics Emeritus at the California Institute of Technology and a 1969 Physics Nobel Prize winner into science:

> My brother Ben was a wonderful influence in my life. Ben was almost nine years old when I was born, and, like me, was three years ahead of most other students in his school. He taught me to read from a cracker box, when I was three. He taught me almost everything I knew when I was little. Ben and I would do all sorts of things together. We played games and we visited museums. We loved bird-watching, and we were also interested in plants, butterflies, giant silk moths, and mammals. We still went up to the Bronx for some of our bird-watching after we moved… At home, the atmosphere was always friendly to science. My father was very devoted to mathematics, physics, and astronomy. He tried to learn advanced physics, particularly general relativity, and was a great admirer of Albert Einstein. (p. 36)

The vastness of the heavens has captivated many future scientists, and Paul C. W. Davies, professor of natural philosophy in the Australian Centre for Astrobiology at Macquarie University in Sydney, waxes picturesque in a tender childhood memory of time spent with his father:

> We walked back home in the dark, through a small wood, and my father pointed out the bright star Sirius and some well-known constellations. I remember vividly the sharp points of light in the blackness of the sky, seen through the skeletal, leafless trees. Then we saw a shooting star. I had already noticed these fleeting objects from our back garden but had taken them to be a strange form of fireworks. My father explained that they were

> meteorites plunging into Earth's atmosphere… From then on, I was hooked on science. (p. 55)

Other projects, often related to his future work, included building a pin-hole camera, a photographic developing kit, a telescope, bows and arrows, firecrackers, and paper airplanes.

Freeman J. Dyson also enjoyed astronomy as a kid, as well as calculating and reading before he eventually became a professor emeritus of physics at the Institute for Advanced Study. His early interests were actually the consequence of a negative learning environment, described below, that illustrates his early scientific curiosity:

> The school was a Dickensian horror, but it had one redeeming feature: a library where I could escape from sadistic boys and a sadistic headmaster. In the library was the Book of Knowledge, a popular children's encyclopedia, and the science were fiction novels of Jules Verne… When I found out that the Verne stories were fiction, it was a big disappointment; I like the Book of Knowledge better, because I could trust it… I read about matter being made up of electrons and protons. Then I read a long piece about electrons and electricity and electric motors, but there was nothing comparable about protons. I wondered why this was: Why didn't we have "proticity" and "protic" motors? I asked some of the boys and some of the teachers, but nobody knew. The school taught mostly mathematics and Latin. No science was taught. That was probably a good thing, as it made science more attractive to misfits like me. (p. 64)

Sometimes it is not the grandeur of Nature but the genius of Man that enthralls the budding scientist. As Lee Smolin, founding member and research physicist at the Perimeter Institute for Theoretical Physics in Waterloo (Ontario), recounts:

> One of my earliest memories is of going on walks with my father across Central Park to observe the progress of the construction on Frank Lloyd Wright's Guggenheim Museum. I also recall a few years later on reading together a popular book on relativity theory, and drawing pictures of trains and lanterns. (p. 72)

Then again, sometimes it is not the genius of Man either, but a relationship:

> I don't recall having much interest in science. In seventh grade I went to a summer enrichment program in science – and I played with magnets, wires, chemicals, all the usual stuff – but I don't recall any of this making much of an impression. I have never in my life taken anything apart to fix it or to see how it works. I became a scientist after all because of two mentors who made everything possible. The first was a friend of the family, William Larkin, a mathematician at Xavier University, who let me play on his department's computer at a time when computers filled large rooms and no one thought a ten-year-old could write a program. (p. 73)

Smolin was remarkably philosophical for a senior in an experimental high school where he heard Buckminster Fuller and took courses in college. After reading a book by Einstein:

> I came to a decision that my life would be dedicated to following the path of Einstein. One of his ideas that appealed to me was that by becoming a scientist you could transcend the pain and uncertainty of ordinary life. By grasping the laws of nature, you connect with an aspect of the world more permanent and beautiful than the short striving of human life. But I also understood somehow that I could do physics. I know I wasn't meant to be mathematician. (p. 76)

A veritable culture permeated by science-related experiences and influences is described by Steven Pinker, not the least of which is a community of learners: "Mother was fascinated by ideas, my father by gadgets. Our house had books, magazines, and the World Book Encyclopedia which I read in its entirety. I read biographies of scientists." (pp. 87-88). Pinker also perused the Time-Life Books, followed science in the news, maintained a train set, assembled science projects, and conducted experiments in electrochemistry: "Peers are paramount in socializing children, and I realize that the most profound influence of my schooling was to put me together with intellectually engaged peers" (p. 88).

Pinker is now a professor in the department of psychology at Harvard.

Mary Catherine Bateson, president of the Institute for Intercultural Studies in NYC and professor emerita at George Mason University, enjoyed trips, camping, and studying biology with her father:

> When I think of him, I think of studying tide pools, collecting beetles, constructing an aquarium, and taking and developing photographs together, but also of logical puzzles and problem solving. He explained Mendelian ratios and diagrammed the different kinds of electrical circuits as we searched for dead Christmas tree bulbs in old-fashioned strings wired in series. His rare letters to me over the years contained little of events or feelings. Instead, they were full of diagrams: the legs of beetles, bubble nests built by fish, the emergence of buds on plants. (p. 93)

It is hard to imagine that Carl Sagan would marry anyone but a wife who shared his passion for studying natural phenomenon. Yet Lynn Margulis' arena of investigation was many orders of magnitude smaller than Sagan's. Presently she is a professor in the department of geosciences at the University of Massachusetts in Amherst, but she first became intrigued by science when she heard a camp counselor talk about amoebas and then studied ants and sow bugs on her front lawn. Exchanging the telescope for a microscope, Margulis reflects that:

> Whether diary entry or essay, jingle or dialog, if I failed to write on any given day I suffered a sense of deprivation. Although I can conceal these solitary and bookish tendencies, I haven't changed much. I grew up, as the cliché says, too fast; I was plunged early into the adult world of responsibility. But I also still enjoy an extended childhood: The love of nature, the interest in the out-of-doors and what lies under the microscope. The curiosity whetted by stimulating discussion has never left my life. (p. 103).

Surprisingly, Margulis never finished high school, but neither did Jaron Lanier, former lead scientist of the National Tele-immersion Initiative studying advanced applications for Internet 2. (Growing up next to Los Alamos, however, more than compensated!) He describes some of the advantages of living in close proximity to a National Laboratory:

> There was a social anomaly in our part or the world: a large population of superb engineers employed in the nearby weapons labs, who were mixed into the otherwise undereducated desert population. It was a huge relief to discover the culture of technical people, which was as welcoming to an awkward kid like me as the psychics were but in a way that was not exploitative. One of our near neighbors was a lovely, slight old man named Clyde Tombaugh, who had discovered the planet Pluto in his youth. When I knew him, he directed research in optical sensing at the White Sands Missile Range. He had built marvelous, huge backyard telescopes, and he let me play with them. I will never forget a globular cluster he showed me – a vividly three-dimensional form, a physical object like me, a cousin to me, as real in front of me as anything else in the world. I gained a sense of belonging in the universe. (pp.116-117)

Lanier later traded the universe of outer space for the universe of cyber space – the internet.

Though his parents were both naturalists, Richard Dawkins, professor of The Public Understanding of Science at Oxford University, came to science late – through books. But his recollections hearken back to a children's book and a principal's radical idea:

> Dr. Dolittle was a scientist, the world's greatest naturalist, and a thinker of restless curiosity. Long before either phrase was coined, he was a role model who raised my consciousness. [About Dr. Dolittle's communication with animals]… It might look like magic, and the bad guys thought it was magic, but there was a rational explanation. (p. 123)

Reinforcing the recurring theme of acquiring mechanical or technical prowess, Dawkins compliments his high school principal. What "should have inspired me, but somehow didn't, was the Week in Workshops. We dropped all normal school work in order to spend an entire week each term in the school workshops" (p. 127).

Sherry Turkle, Professor in the Program in Science, Technology, and Society at MIT, spent time with her grandfather building with plastic bricks and reading books – Nancy Drew mysteries and travel guides (a way to solve geographical mysteries?). In an introspective aside, she muses:

> If there is a sense of vocation to become attentive to the detail of other people's narratives, mine was born in the smell and feel of the memory closet. That is where I found the musty books, photographs, high school class notes that made me feel connected. That is where I determined that I would solve mysteries, that I would use objects as my clues to the heart of the matter. That is where I decided that when the objects could not tell a full story, I would find a person willing to talk to me before a voice was silenced – before someone was forever cut out of the picture. (pp. 151-152)

Not all of the scientists felt that their childhood was pivotal in their eventual pursuit of a career in science. For example, Marc D. Hauser, Harvard College Professor of psychology, couldn't recall a single early childhood event that led to his current interests:

> I was far more interested in sports, fiction, music, food, movies, and friends. I did, however, have the great fortune of good genes and a great environment. My phenotype is the outcome of a mother who was a compassionate nursery school teacher and a father who was a world-class physicist [Bell Labs] and one of the most voracious intellectuals I have ever met. My childhood was a Renaissance feast of opera, film, philosophy, literature, travel, food, and science. I didn't know any of this when I was five or ten or even fifteen. I know it now. (p. 153)

At the other end of the spectrum was Ray Kurzweil**,** inventor, entrepreneur, and author. Books, especially the *Tom Swift, Jr.* science fiction stories, inspired him as the following account implies:

> The concept in each of the thirty-three books in the series was always the same: Tom would get himself into a terrible predicament. The fate of Tom and his friends, and often of the rest of the human race, hung in the balance. Tom would retreat to his basement lab and think about how to solve the problem. The moral of these tales was simple: The power of the right idea will always overcome a seemingly overwhelming challenge. (pp. 164-165)

Kurzweil also built a rocket ship with an Erector set, and constructed go-karts, boats, a robotic theater, a mechanical baseball game, and a magic box.

Some of the “good genes” Hauser mentioned came from Kurzweil’s mother who was a Ph.D. chemist, and a grandfather who recounted the time he handled an original manuscript by Leonardo da Vinci:

> He described the experience with reverence, as if he had touched the work of God himself. This then, was the religion I was raised in: veneration for human creativity and the power of ideas. At the age of five, I decided I would become a scientist. (p.163)

Later on in his life, his tinkering was scaled down:

> At age twelve I became fascinated with electrical switches and lights. I built my own circular switches – dials that could connect an input to one of ten possible outputs – and created a calculating system that could perform a variety of computations using tiny light bulbs for output. There was something missing, however, in that I was unable to make this system really think on its own. It was then that my Uncle George gave me some surplus electrical relays from Bell Labs and explained how they worked… This encounter with the electrical relay was a true epiphany for me… (p.166)

In high school, Kurzweil hung around the surplus electronics stores and had a summer job computing statistical analyses for research using calculators and spreadsheets. That was when he first programmed a computer. Particularly memorable were family conversations:

> The intense and animated discussions were invariably about new ideas, usually those of intellectuals I had never heard of. The way for me to get attention was to have an idea. And since it was challenging to break into the conversation, it helped if the idea had a material form. There was great respect for learning and accomplishment in my family, so any instantiation of knowledge got their attention. (p. 166)

Janna Levin, professor of physics and astronomy at Barnard College of Columbia University, also had a scientific pedigree. Her father was a medical doctor, and she was consequently able to witness an open-heart surgery. She enjoyed "Star Trek" and other science fiction TV, Carl Sagan and "Cosmos," and the numerous books her mother read to her. She also especially relished the family discussions:

> After Dad came home, the family would sit around the kitchen table and talk – but not about the hospital or the kids in intensive care. We'd talk about things at random. If the conversation needed flint, there was always Carl Sagan. (p. 74)

Then there was the time for reflection and meditation:

> I'd sit up at the foot of my bed to look out the window onto the backyard. I'd listen to the neighborhood. Far off, I would hear cars or trucks moving along, and there were insects worth listening to, all of it providing a sound track to my late-night solitude. I'd stare at the patch of sky wedged between the trees arching over the neighbor's manicured lawn. I'd wonder how far I was seeing, how deep into space. (p.176)

If Dawkins came to science late, then Rodney Brooks, director of the MIT Computer Science and Artificial Intelligence Laboratory and a professor of computer science at MIT, arrived extremely early:

> My father was a telephone technician, and my mother had been a hairdresser… Within that milieu, by age four, I was known as the Professor. I had an uncanny ability to manipulate numbers in my head…I had an obsession with the regularity of arithmetic – with the way numbers made patterns that could be predicted and could be executed within my head through application of procedures I would devise. I had lots of computational ability, but not much to apply it to. (pp.177-178)

When he wasn't doing mental math, Brooks was in the garage woodworking, performing chemistry and electricity experiments with his brother, building switches and a tic-tac-toe machine, and reading a book entitled *Giant Electronic Brains*. Like one of his computers, he was "programmed" in that:

> By age eight, my life's work was determined; I would make machines do things that only people could do by thinking – and I would make those machines do the things that I was very good at doing myself… By the age of ten or so, I had very little doubt that we human beings were machines in the way we thought, and that emulating human intelligence with a machine was just a matter of circuit complexity. (p.179)

Hands-on activities were also crucial for J. Doyne Farmer's emerging into a scientist (a professor of chaos and complexity theory at the Santa Fe Institute). His dad was an engineer and fixed everything, causing Farmer to observe:

> From his example, I naturally assumed that building things was what people were meant to do. So I built lots of things, from soapbox-derby racers to a small house in the backyard. By the time I was ten or eleven, a friend and I had built at least ten tree houses or forts, to provide protection… (pp.183-184)

He later saw the James Bond movie "Thunderball" and began to read up on the rocket pack featured in the film. He also joined the Boy Scouts. This motley assortment of events intersected when:

> One evening a man named Tom Ingerson, in his twenties, came to a troop meeting and was introduced to us as a physicist. I was not exactly sure then what a physicist was, but I know it was what Albert Einstein had been. Cool! Tom would be helping to run the scout troop… I walked home with him and asked him for advice on my rocket pack. He

> suggested some ideas of a more modest kind… A good deal of our lives is determined by chance… He was full of ideas, and he talked about everything under the sun. His intellectual passions spanned a huge gamut, from science to history to archaeology…. He could do calculations in his head at blinding speed, and his brain was paced full of facts… Tom's books also opened up a new world for me. (p.184)

Farmer rounded out his boyhood by reading science fiction, repairing a motorcycle when only 13, tinkering with electronics, and taking trips to a gold mine.

While conducting experiments with a pendulum in high school, Steven Strogatz, professor of theoretical and applied mechanics at Cornell University, had a coruscation:

> I remember experiencing an enveloping sensation of fear, then of awe. It was as if…this pendulum knew algebra! What was the connection between the parabolas in algebra class and the motion of this pendulum? There it was, on the graph paper. It was a moment that struck me, and it was my first sense that the phrase "law of nature" really meant something. I suddenly knew what people were talking about when they said that there was order in the universe, and that, more to the point, you couldn't see it unless you knew math. It was an epiphany I've never really recovered from. (p. 194)

For Tim White, professor in the Laboratory for Human Evolutionary Studies at the University of California at Berkeley, the "scientific moment" was not an instant but a gradual awakening. He recounts:

> Living on the edge of the forest opened the natural world to me in amazing ways. My younger brother Scott and I tried to domesticate mountain squirrels, a raccoon, several pigeons, blue jays, chipmunks, tortoises, turtles, and lots of snakes and lizards that shared the house and yard with the family dachshund. Rattlesnakes we were allowed to kill, but

> not to bring home alive. There were always terrariums and cages in the backyard, and most of our pets hibernated in the basement during the winter. Scott and I also had a donkey named Bimbo. (p. 204)

Because his father was a road engineer, he would bring home unusual rocks from construction sites. They would also spend weekends as a family on the road exploring the "country in all of its natural, historical, and geographic dimensions. We all learned together on those trips." (p. 205). Books also played a vital role:

> While my brother swam and my parents sunbathed, I hunted lizards in the rocks, listened to LA Dodgers games on a transistor radio, and read many books. My favorites were the Time-Life books on natural history my grandmother had given us. The text and pictures made accessible the natural world that surrounded and fascinated me. (p. 206)

Additionally, White's family became adept at looking for dinosaur bones, finding archeological sites, keeping records, reading topological maps, and getting around in the wilderness. In a moment of reverie he asks,

> So what made the kid choose a life in science? It was freedom. My parents never pushed me in a career direction. For this freedom I cannot thank them enough. I inherited their skepticism…, their fascination with things historical and natural, their curiosity. The opportunity for a kid to grow up in the mountains came only because my parents were young and willing to take a risk, to seek a better and more interesting life. I was the luckiest kid in the world, a privileged passenger along for the ride of his life. (p. 208)

A socially awkward child, for V. S. Ramachandran, professor in the psychology department and the neuroscience program at the University of California, San Diego, science provided a retreat into a private world, one made possible, again, by encouraging and enabling parents. He speculates:

> Science is a love affair with nature – a love affair that has all the obsessive qualities, the turbulence, the passionate yearning that one commonly associates with romantic love. But where does this yearning come from? To some extent, it is probably an innate personality trait. But more important, it arises from your early associations. I realized a long time ago that the best formula for success is to be around people who are passionate and enthusiastic about what they do, for there is nothing more contagious than enthusiasm… It helps, too, to have parents like mine, who constantly goad you to excel and who stimulate rather than stifle your natural curiosity. Knowing my interest in science, my mother brought me seashells and other zoological specimens (including a tiny seahorse) from all over the world and helped me set up a chemistry lab under our staircase. When I was eleven years old, my father bought me a Carl Zeiss research microscope. (pp. 211-212)

Daniel C. Dennett, professor of philosophy and director of the Center for Cognitive Studies at Tufts University, had a father who was a Harvard historian, but confesses that:

> I had lots of adventures when I was a kid, but none of the kind that would prepare me for a life on the edge of science. None of my many mentors was a scientist, and I had no scientific epiphanies until I was in graduate school. (p. 219)

Yet seeds were sown and a climate conducive to learning was created during his childhood. In fact, a case could be made that one of his mentors was the housekeeper. He remembers that:

> She and Mother often disagreed, and my sisters and I participated vigorously in their suppertime conversations. We had a rule at the dinner table: The only reason for being

> excused in the middle of the meal was to go look up some point of contention in the World Book or other reference work. There were frequent consultations. Our home was full of books and magazines, and after school, when I wasn't reading I was drawing, constructing, rebuilding things in my basement workshop or in my attic bedroom, where I kept all the small tools for sculpting and drawing, along with my gigantic chest of several Erector sets and the extraneous machine parts that might come in handy someday. I shunned all the diagrams and instructions that came with the Erector sets, preferring to strike out on my own and make something original. From the age of five, I was fascinated with taking things apart and repairing things, but the question of whether I might want to become an engineer never came up. (p. 221)

Perhaps it was a negative experience (unreported) in biology class in high school that sent him through a jazz musician stage, artist stage, sculptor stage, and a teacher stage. But,

> In spite of this, I had a subscription to *Scientific American* for several years from the age of about twelve, and every month I'd pore through it, usually just looking at the diagrams and pictures and reading the captions. I loved the ideas, but never thought of becoming a scientist. It was only in graduate school. (p. 225)

The last scientist to recount her story in Brockman's book is Judith Rich Harris, a developmental psychologist. She recollects turning to reading for solace and hanging around brainy kids in school but gives scant recognition to her relationship with, or the atmosphere created by, her parents or teachers:

> What made me become a scientist and writer? Genetic factors are no doubt involved. I seem to have been born with the predispositions to love reading and to thumb my nose at authority. But what environmental factors were influential? Not my parents. They were

> not "role models" for me… Not my teachers, either. I can't name a single teacher, from nursery school through graduate school, who had an important influence on me. (p. 234)

This seems odd when just a few pages earlier she described a characteristic in them that likely helped to pave the way for her professional interest.

> My parents were permissive when it came to pets; I kept animals of all kinds. In addition to the usual dogs and cats, there was a lizard, a horned toad, turtles, a rabbit, a kangaroo rat, hamsters, hooded rats, a parakeet, and a baby robin that we raised successfully. (p. 230)

In concluding this subsection of biographies and autobiographies, Harris's question (p. 234) remains unanswered. Is it genes ("nature"), or environmental factors ("nurture"), or some other influence alluded to by some of the other scientists, such as circumstances ("luck") or something innate ("calling")? Before this conundrum is considered further in chapter 6, one last data stream needs to be evaluated.

Oral Archives

The last location mined for information about how high school science-related experiences influenced career persistence was electronic, one of which was a web site entitled *Echo*, an oral archive developed by George Mason University. (http://echo.gmu.edu/surveys/contributions.php?survey=wscience). Among its many resources was an online survey that "allows women to tell about their careers in their own words, recording the experiences of women scientists and engineers permanently." Since the first submission in November of 2001, 133 woman scientists (as of the date of this dissertation) have visited this site to answer ten questions about their careers. (All quotes are in the appendixes and come from this site. The number at the end of the quote refers to the number of the survey in the database.)

Though not all the questions were relevant to this dissertation, the source provided some contrast and balance since most of the biographies were of males, many of whom were retired or deceased. The question that most frequently provided the vast majority of reflections relevant to this research was the first one, which asked "Were you encouraged, as a girl, to pursue a career in the sciences? Whether you answer yes or no, please elaborate on the nature of the encouragement/discouragement." Obviously, given the nature of this question and several others in the survey, the emphasis was on encouragement, especially in the context of gender bias. It should be noted that responses are taken at face value since a survey (unlike an interview) does not afford an expeditious way to corroborate or probe the accounts more deeply. Each scientist's name, a description of her high school, the school from which each received her degree, whether or not that degree was a doctorate, and the research specialty were not provided.

Thirty of the respondents noted that their fathers were scientists or engineers, 17 said their mothers were scientists or engineers (fourteen of this group said both parents were) and nine mentioned other family members such as grandparents, uncles, and brothers. An additional 38 fathers, 44 mothers (31 said both), and thirteen relatives and friends were not specifically mentioned as scientists but were singled out as having provided encouragement to pursue careers in science.

Encouragement came in a number of different forms, including personal tutoring or helping with homework, advocacy at school in getting into math/science programs, discussions at the dinner table, visits to colleagues who were professionals, trips to museums, walks in the woods, gifts of scientific "toys," support of science projects such as insect collections, and financial assistance. Special note should be made of the attitudes and character traits fostered by parents such as wonder, curiosity, perseverance, hard work, and striving for excellence. Most of all, they were excellent examples and role models. Their quotes, found in Appendix E, illustrate both the positive influence of parents and the means by which they created a supportive atmosphere conducive to scientific curiosity.

Thirty-nine teachers were identified as giving significant encouragement. Again, because of the limitations of a survey, the elucidation of the nature of this encouragement, particularly as it relates to the classroom and pedagogical practice, was not possible. It is probably safe to assume by the context that it was often in the form of overcoming gender bias. However, it should be noted that the encouragement frequently took place in the context of a private conversation about future majors and careers. Only those quotes which provide specifics are recorded in Appendix F.

On the other side of the ledger, three fathers, four mothers, and four teachers tried to discourage these scientists from entering a scientific career. Added to this were 24 accounts of being discouraged by others, including two schools in general and nine guidance counselors in particular. Not surprisingly, more of these disparaging remarks reveal gender bias than any other teacher shortcomings. Because these negative recollections can also inform about what *not* to do and say, they are recorded in Appendix G.

Eighteen scientists recalled special science-related experiences that influenced them during their pre-college education. Included in this list were summer programs (4), science clubs (4), competitions (4), computers (4), science fairs (2), insect or leaf collections (2), and service experiences such as being a lab aid (2). Altogether, five scientists mentioned more than one experience. Some of the references to these activities have already appeared in the previous quotes. Additional ones can be found in Appendix H.

Math, reading, computers, and taking rigorous courses in general were also influential factors, with math being specifically spotlighted 18 times and reading seven times. Advanced Placement (or honors) courses were referred to nine times, and Brooklyn Technical High School with its special math/science emphasis was the only school specifically named (twice). Not surprisingly, several Nobel Prize winners singled out this same high school earlier. The importance of math as a precursor to a career in science should already be evident by the frequency of its mention in the earlier quotes. A few more are given, including a very impassioned plea, in Appendix I.

Though not mentioned quite as frequently, the importance of being a part of a small support group and the value of having some kind of mechanical (technical or "hands-on") experience are both significant. The quotes demonstrating this are in Appendix J.

Summary

In concluding this subsection of the analysis of online autobiographical comments ("oral archives") about the science-related experiences of women scientists, several observations can be made in summary of the biographies and autobiographies. First, encouragement at any level and for any endeavor (not just science) is paramount. Related to this is the second observation – relationships are essential, whether they are with parents, teachers, mentors, or peer groups.

The third observation is that creating a rich and conducive learning environment is multi-faceted and incorporates diverse people, places, things, experiences, and strategies. Some of them include access to books, the development of math skills, opportunities to use tools and build things, availability of toys that are "hands-on" and allow for creative construction, and visits to learning environments (e.g., museums, laboratories, forests, the ocean).

The fourth observation follows from the third. There is no single “formula” that will inexorably result in a scientist (or any other professional), but there are certain approaches to encourage and others to avoid. Finally, the obstacles to entrance into science are formidable enough without adding such horrendous hurdles as gender bias and stereotyping, poverty of opportunity, inferior education, and perhaps most of all, broken or non-functional families.

How these five observations relate and are incorporated into the way in which high school science-related experiences influenced science career persistence is the task of Chapter Six.

CHAPTER 6

Conclusions

Introduction

The challenge of improving science education and thereby increasing the number of scientists in the United States is old, deep-seated, and, by some accounts, intractable. It is certainly not going to go away on its own nor lend itself to quick fixes. The major difference between how the problem was framed a decade ago and how it is framed today is not one of substance but one of urgency. In a democratic society that is dependent upon science and technology to (1) maintain its economy and, more importantly in light of the events surrounding 9/11, to (2) guard its freedom and ability to thwart the efforts of terrorists, the importance of solving this crisis has never been greater.

The long-term solution is multi-faceted and will require the concerted efforts of citizens, educational institutions, business and industry, and all levels of government. This research, with its limited focus on high school, does not purport to solve all the problems within science education, much less the greater challenges facing this nation. It does, however, contribute to a better understanding of how to approach both these challenges and problems.

Towards this end, the purpose of this study was to investigate how high school science-related experiences influenced some practicing scientists. Along the way, this study hoped to shed some light on those practices and experiences that propelled or obstructed their pursuit of a career in science. Finally, and tangentially, this study attempted to provide a little insight into whether or not there were any practices in high school science classes that deterred women and minorities from seeking a career in science.

This final chapter will be organized around the four principle research questions and the two subsidiary questions. After repeating each question, the data on that specific issue will be summarized. Later, recommendations will be made, and areas for further research will be identified.

Research Question One

The first research question was "How did practicing scientists' personal relationships with their science teachers influence their decision to pursue a career in science?" The data reveal a broader context for this question. *Many* relationships (e.g., parents and family members, peers, and mentors) play a critical role, not just the scientist's relationships with science teachers. The data also imply that these relationships are so influential that they represent some of the most significant determinants for career persistence in science. Finally, the data show that while some scientists felt they were destined (by genes, social environment, or design) to be scientists from early on, many enjoyed ongoing nurture and support from multiple individuals, usually including science teachers.

This nurture and support comes under the umbrella terms of *passion* and *compassion*. Indeed, these endearing traits and their subsequent delineations are hallmarks of *all* good teachers in *all* disciplines. Nevertheless, as described by the scientists in their interviews, the science teacher's *passion* for science and teaching is itemized in the following manner:

1. Influential teachers are *contagious.* Scientists recalled their favorite and most influential teachers as being enthusiastic, dynamic, excited, energetic, inspirational, and passionate about their discipline. These teachers loved to teach and loved what they were teaching, and this enthusiasm was infectious.

2. Influential teachers respect the science *content*. They study it, understand it, communicate it well, make it lively and relevant, and enable students to see it in context and thereby appropriate it as their own. They prepare the students for the rigors of a science major in college.
3. Influential teachers *challenge* the students. They set high standards and then guide the students as they achieve them. They teach students to wrestle and persevere, to live with the inherent tension and frustration of not knowing all the answers to scientific conundrums. They push the students out of their comfort zones and then guide them towards mastery.
4. Influential teachers not only have character (are role models) but they are *characters.* They take advantage of their personal quirks and idiosyncrasies to create an enjoyable and thriving learning environment. They are engaged, but engaging.

The science teacher's *compassion* for his/her students is fleshed out in a multitude of ways that overlap each other, and can be encapsulated by the following statements:

1. Influential teachers genuinely *care* about their students and their students' learning. They discern each student's strengths and weaknesses and create an intimate and collegial learning environment.
2. Influential teachers *respect* their students and teach and act in such a way that their students have cause to respect them. They accomplish this by knowing their students and knowing their science. They seek out learning experiences for themselves (professional development) and create them for their students. They work at forging relationships with their students, and they work at adequately preparing their students for the next level.

3. Influential teachers *discipline.* They are themselves disciplined (consistent, professional, and under control), and they constructively discipline their students. Through effective classroom management, they create a fair and safe learning environment that is conducive for each student reaching their potential.
4. Influential teachers *encourage.* They help students overcome difficulties, both personal and scholastic, and weather the vicissitudes of adolescence and academics. In this enterprise especially, they join parents, peers, and mentors in what is perhaps the most prevailing influence for persistence in science.
5. Influential teachers are *involved* in the lives of their students and the life of the school as much as possible. They often coach (or go to games), are available outside of the classroom, and creatively generate extracurricular opportunities to interact with students.

Research Question Two

The second research question was “What pedagogical methods (e.g., lectures, demonstrations, “hands-on” work, problem solving, small groups) used in their high school science courses, if any, played a significant role in propelling certain students towards a career as a practicing scientist?” In other words, did particular pedagogical methods positively influence the decisions of high school students to become scientists?

The answer to this question is that *all* pedagogical methods (e.g., hands-on activities, demonstrations, labs) made a difference, but with certain caveats attached.

1. The first caveat is that teachers have different personalities, gifts, and strengths. Therefore, teachers utilize different pedagogical methods with various levels of success. Teachers should know which style most suits them but become adept at the others for the reasons stated below.

2. The second caveat is that students have different learning styles, backgrounds, and maturation rates. Teachers must know their students and adapt their pedagogical approaches accordingly. Teachers must also assist students to learn how to learn even when the teaching and learning styles are not synchronous.
3. The third caveat is that a combination of approaches is better than only one and that different lessons lend themselves to different approaches. In short, there is no "one size fits all." This takes intention and planning on the part of the teacher.

The interviews revealed some valuable insights about how demonstrations, labs, and activities should be conducted in order to maximize their benefit and influence. In particular, these conclusions should be considered when problem-based-learning-environments (PBLE's), first mentioned in the review of the literature, are designed and implemented.

1. *Demonstrations:* Demonstrations make the theoretical real and tangible, and promote the maturation of naïve ideas. They serve the *short-term* purpose of incubating an interest and excitement about science in the student at a time when there are a surfeit of competing interests clamoring for attention. They serve the *long-term* purpose of creating a vivid memory that reminds the scientist about why they pursued a career in science in the first place. Demonstrations should work, should be instructive and not merely entertainment, should flow from the curriculum, and should not drag on.
2. *Labs:* Much of what was just stated about demonstrations is also true of labs. Important codicils include the conviction that more labs should be open-ended and investigative (depending on the prior knowledge of the student), integrated into the course, and appropriately evaluated. Too many labs are pedantic and "cookbookish." The more challenging and time intensive part of doing labs – writing them up – is a valuable

experience but potentially discouraging if the student does not trust the teacher and his/her rationale for doing it.

3. *Hands-on Activities:* Again, much of what was just stated about demonstrations and labs is also true of hands-on activities. If demonstrations are at the teacher-centered end of the spectrum, and labs are at the more student-centered end of the spectrum, hands-on activities are in the middle. In view of the changing social landscape, in which students are less likely to have grown up on a farm or played with toys like erector sets and chemistry sets, hands-on activities (in which students literally manipulate and construct things) are more important than ever.

Research Question Three

The next research question was "What high school science-related support structures (e.g., labs, equipment, textbooks, technology), if any, played a significant role in propelling certain students towards a career as a practicing scientist?" In other words, did certain facilities or materials positively influence the decisions of high school students to become scientists?

The answer to this question is similar to the answer to the last question. Laboratories, equipment, textbooks, and technology, et al., are all potentially influential. But the extent of their influence is predicated upon (1) the learning style of the student, (2) the effective (or ineffective) use of them by the teacher, and (3) the quality of the structure itself. A good teacher can be influential even in the direst of circumstances, and a poor teacher negates any advantages that an abundance of resources might confer. However, in the hands of a skilled teacher, such structures are powerful motivators and tools that can facilitate and enhance the student's progress towards a scientific career.

Most of the scientists foresee the tremendous influence that technology will be in the future but were too far along in their education to have availed themselves of it during high school. Nonetheless, these structures were the least influential in terms of the amount of discussion given to them by the scientists.

Research Question Four

The final research question was "What high school science-related educational activities (e.g., science fairs, clubs, summer internships), if any, played a significant role in propelling certain students towards a career as a practicing scientist?" In other words, did certain co-curricular or extracurricular opportunities positively influence the decisions of high school students to become scientists?

There is no question that the aforementioned activities were powerfully influential for those students who had the opportunity to experience them. A large part of the benefit was due to the relational component that occurs when, for example, the student is working with a parent on a science fair project or teaming with a scientist during a summer research program. Other benefits included the hands-on experience, the authentic nature of the research, the increased knowledge and confidence that comes from collaborating with professional scientists in a professional and real-world environment, and the exposure to science career possibilities.

Secondary Question One

The first subsidiary question was "Did women or minorities encounter significant support structures or, conversely, obstacles in their science-related experiences that affected their pursuit of science as a career?" Though this was not the main focus of the study, the data did show that, at the very least, the factors that positively influenced scientists to pursue and persist in science careers while they were in high school, could benefit everyone, regardless of race, gender, or socioeconomic background. Significantly, all of the minority scientists and all but one of the women scientists reported at least one family member who was supportive of their scientific proclivity while growing up.

The obstacles, if any, experienced by the women scientists most frequently consisted of lower career expectations, especially by guidance counselors. The obstacles faced by minority scientists most frequently consisted of limited access to science-related opportunities, either due to difficult family situations or obstructive school circumstances.

Secondary Question Two

The other subsidiary question was "Did access to technology (e.g., audio-visuals, computers, internet, graphing calculators, electronic data-gathering devices) – technology that was more readily available to younger scientists when they were in high school than to older ones – significantly influence certain students in their pursuit of science as a career?"

Little light was shed on this query primarily due to the fact that the scientists attended high school well before most of the technology (especially computer-related technology) that is expected to have a significant impact on education became widespread. This was, of course, because of the fact that so many years of education and preparation elapse between high school and finally becoming immersed in a science career, even for the youngest of scientists. At best the technology was only in its rudimentary forms. However, because of their exposure to state-of-the-art technology as a part of their research, many of the scientists had high expectations as well as genuine concerns about its increasing integration and influence.

Future Research

A number of interesting research questions were generated by the interviews as the scientists reflected on their past experiences related to science while they were growing up. They include:

1. Now that technology has become commonplace and affordable in most high schools, what is the influence of technology that has been fully integrated into the science curriculum on science career persistence? (Even the youngest scientists in this study did not benefit from the extent of the technological change that is now commonplace in high school.)
2. Sooner or later, $100 textbooks will be replaced entirely by the electronic textbook – a DVD or similar technology. How will the teacher and student use them, and will they be used any differently (or any more) than conventional textbooks were used?
3. What is the long-term impact on science career persistence of performing virtual labs (e.g., dissection) compared to real labs?
4. Which is more effective (as far as interest in science and career persistence is concerned) in the elementary classroom – being taught by a specialist or being taught by the same teacher (who has received some science training) but also teaches most everything else?
5. What are the long-term effects (as far as interest in science and career persistence is concerned) of regularly being read to at home before some cutoff date (such as third grade)?
6. What are the long-term effects (as far as interest in science and career persistence is concerned) of playing with video games while growing up instead of the more traditional manipulative toys like Legos and blocks?

7. Are students who take honors, advanced, or AP (Advanced Placement) and IB (International Baccalaureate) science courses more likely to pursue and persist in a career in science than those who do not take these courses?
8. What has been the effect of living in a litigious society on the use of potentially dangerous science toys like chemistry sets and model rockets?
9. What educational approaches, activities, and structures can a school encourage that are particularly effective in offsetting (at least partially) the pernicious effects of the deprivation of encouragement and opportunity that too frequently stems from broken homes and/or poverty?
10. What programs can the government initiate or promote (e.g., tax breaks to science-related industries; grants to universities and government labs) that will more effectively provide students and science teachers with meaningful science-related internships and research experiences?
11. How can college and university teacher-education programs be improved to enable future science teachers to be more effective in forging relationships (e.g., encouragement) and in teaching science (e.g., mastering different pedagogical styles)? How can college and university teacher-education programs be improved to enable *all* science teachers to keep up with the latest technological innovations, improve their skills, and learn about the latest developments in their respective sciences?
12. How can the school calendar be changed in order to facilitate more opportunities for students to experience collaborations, internships, PBLE’s, and other authentic research opportunities?

13. How can the school calendar be changed in order to facilitate more opportunities for teachers to experience ongoing collaborations, internships, and other professional development and authentic research opportunities?

Closing Remarks

The more fundamental and encompassing question than "How did high school science-related experiences influence science career persistence?" is "What makes a scientist in the first place?" After all, some of the scientists knew they were going to go into science (or were extraordinarily interested in science) even before they entered middle school. Others did not decide to pursue a career in science until after college.

For those scientists who knew early on, their interviews revealed the following four "causes." Some of the scientists invoked a hereditary explanation. They used phrases such as "from the beginning," "I was wired this way," and "I had a natural bent." This could be considered the so-called *nature* factor.

Other scientists attributed their interest in science to the environment in which they grew up, crediting parents, other individuals, or surrounding opportunities. This could be classified as the so-called *nurture* factor.

Perhaps in the same category as this were those who chalked it up to chance, fortuitous events, or simply said, "I was lucky." For example, a number of the scientists experienced a childhood disease that not only made the pursuit of competing interests difficult, it fueled a desire to understand their infirmity.

Finally, some of the scientists felt they were "programmed" or "destined" to be a scientist. This was attributed to a "force," a "drive," or a "dream" that had no physical origin. In several cases, the Giver of this "gift" (talent, ability in science) was ascribed to God.

Regardless of the etiology, the high school science-related experiences of the scientists, especially as they encompass the relationships with their science teachers and the learning environment these teachers created, were significant. Such positive influential experiences encouraged and reinforced the science focus for those students who were already predisposed to a career in science. *Thus they were not lost to the profession.* These same positive and influential experiences acquainted and excited those students who were not yet settled on a direction, and introduced them to the rewards of a career in science. *Thus they gained entrance into the profession.*

REFERENCES

Abraham, L. (2002). What do high school science students gain from field-based research apprenticeship programs? *The Clearing House, 75*(5), 229-232.

Andre, T., Whigham, M., Hendrickson, A., & Chambers, S. (1999). Competency beliefs, positive affect, and gender stereotypes of elementary students and their parents about science versus other school subjects. *Journal of Research in Science Teaching, 36*, 719-747.

Atwater, M. M., & Wiggins, J. G. (1995). A study of urban middle school students with high and low attitudes toward science. *Journal of Research in Science Teaching, 32*, 665-677.

Barab, S. A., & Hay, K. E. (2001). Doing science at the elbows of experts: Issues related to the science apprenticeship camp. *Journal of Research in Science Teaching, 38*, 70-102.

Bauer, C. F. (2002). What students think. *The Science Teacher, 69*(1), 52-55.

Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching, 40*, 487-509.

Berg, B. L. (2001). *Qualitative research methods for the social sciences* (4th ed.). Boston: Allyn and Bacon.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*, 369-398.

Bonous-Hammarth, M. (2000). Pathways to success: Affirming opportunities for science, mathematics, and engineering majors. *Journal of Negro Education, 69*(1/2), 92-111.

Brazziel, M., & Brazziel, W. (2001). Factors in decisions of underrepresented minorities to forego science and engineering doctoral study: a pilot study. *Journal of Science Education and Technology, 10*(3), 273-281.

Brockman, J. (Ed.). (2004). *Curious minds: How a child becomes a scientist*. New York: Pantheon.

Byrne, L. (2000). *Where worlds of children and science meet*. Burnaby, B.C.: Science Council of British Columbia.

Cavallo, A., Sullivan, C., Hall, N., & Bennett, M. (1999). Promoting participation in the health science professions: Summer programs for talented, underrepresented students in science. *School Science and Mathematics, 99*(6), 294-301.

Chandler, F. T., & Parsons, S. (1995). *A case study of a mother/daughter science club*. Unpublished manuscript, San Francisco, CA.

Cooper, R. A. (2003). Impact of trends in primary, secondary, and postsecondary education on applications to medical school. II: considerations of race, ethnicity, and income. *Academic Medicine, 78*, 864-876.

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Culotta, E. (1992, Nov. 13). Scientists of the future: Jumping high hurdles. *Science, 258,* 1209-1210,1213.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2000). *The handbook of qualitative research* (2nd ed.). Thousand Oaks, CA: Sage.

Didion, C. J. (1996). Motivating women students. *Journal of College Science Teaching, 25*, 439.

Entwisle, D. R., & Hayduk, L. A. (1988). Lasting effects of elementary school. *Sociology of Education, 61*(3), 147-159.

Etkina, E., Matilsky, T., & Lawrence, M. (2003). Pushing to the edge: Rutgers astrophysics institute motivates talented high school students. *Journal of Research in Science Teaching, 40*, 958-985.

Evans, M. A., Whigham, M. M. & Wang, C. (1995). The effect of a role model project upon the attitudes of ninth-grade science students. *Journal of Research in Science Teaching, 32*, 195-201.

Farenga, S. J., & Joyce, B. A. (1998a). Development and analysis of a scale to assess students' out-of-school science-related experiences. *Education, 118*(3), 381-383.

Farenga, S. J., & Joyce, B. A. (1998b). Science-related attitudes and science course selection: A study of high-ability boys and girls. *Roeper Review, 20*(4), 247-251.

Farenga, S. J., & Joyce, B. A. (1999). Intentions of young students to enroll in science courses in the future: an examination of gender differences. *Science Education, 83*, 55-75.

Farmer, H., Wardrop, J., & Rotella, S. (1999). Antecedent factors differentiating women and men in science/nonscience careers. *Psychology of Women Quarterly, 23*, 763-780.

Feldman, A., Konold, C., & Coulter, B. (2000). *Network science a decade later: The internet and clasroom learning*. Mahwah, NJ: Lawrence Erlbaum.

Feldman, G. (2001). Encouraging mentorship in young scientists. *New Directions for Child and Adolescent Development, 93*(Fall), 61-71.

Fogg, P. (2002). Number of U.S. doctorates awarded falls, but women gain share of total. *The Chronicle of Higher Education, 49*(13), A13.

Fontana, A., & Frey, J. H. (2000). The interview: From structured questions to negotiated text. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 645-672). Thousand Oaks, CA: Sage.

Freedman, M. P. (1998). Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal of Research in Science Teaching, 34*, 343-357.

Gavin, K. (1996). The development of math talent: influences on students at a women's college. *Journal of Secondary Gifted Education, 7*(4), 476-486.

George, R. (2000). Measuring change in students' attitudes toward science over time: An application of latent variable growth modeling. *Journal of Science Education and Technology, 9*(3), 213-225.

George, R. (2003). Growth in students' attitudes about the utility of science over the middle and high school years: Evidence from the longitudinal study of American youth. *Journal of Science Education and Technology, 12*, 439-448.

George, Y. S., Neale, D. S., Van Horne, V., & Malcom, S. M. (2001). *In pursuit of a diverse science, technology, engineering, and mathematics workforce: Recommended research priorities to enhance participation by underrepresented minorities*. Washington, DC: American Association for the Advancement of Science.

Gibson, H. L., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education, 86*, 693-705.

Gibson, H. M., & Francis, L. J. (1993). The relationship between television viewing preferences and interest in science among 11-15 year-olds. *Research in Science & Technological Education, 11*(2), 185-191.

Gilroy, M. (2002). Waking up students' math/science attitudes and achievement. *The Education Digest, 68*(4), 39-44.

Goldman-Segall, R. (1998). Gender and digital media in the context of a middle school science project. *Meridian, 1*(1).

Griffin, J. (1991). Learning science through practical experiences in museums. *International Journal of Science Education, 20*, 655-663.

Hammrich, P. (1997). Sisters in science: Promoting females' success in science. *Classroom Leadership, 1*(4), 1-4.

Hansen, W. (1996, August). Overview of technical papers. From *Careers in science and technology: An international perspective* (pp. 79-80). Washington, DC: National Academies.

Herbold, R. J. (2004). *Sustaining the nation's innovation ecosystem: Maintaining the strength of our science & engineering capabilities*. Paper presented at a meeting of the President's Council of Advisors on Science and Technology, Washington, DC.

Hofstein, A., & Lunetta, V. N. (2003). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*, 28-54.

Horn, L., & Kojaku, L. (2001). *High school academic curriculum and the persistence path through college: persistence and transfer behavior of undergraduates 3 years after entering 4-year institutions*. Washington, DC: National Center for Education Statistics.

Hunt, E., & Minstrell, J. (1998). A Cognitive approach to the teaching of physics. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory* (pp. 51-74). Cambridge, MA: MIT Press.

Hurd, P. D. (1997). *Inventing science education for the new millennium*. New York: Teachers College Press.

Hurd, P. D. (1998). Linking science education to the workplace. *Journal of Science Education and Technology, 7*, 329-335.

Jayaratne, T., Thomas, N., & Trautmann, M. (2003). Intervention program to keep girls in the science pipeline: outcome differences by ethnic status. *Journal of Research in Science Teaching, 40*, 393-414.

Jones, M. G., Howe, A., & Rua, M. J. (2000). Gender differences in students' experiences, interests, and attitudes toward science and scientists. *Science Education, 84*, 180-192.

Joyce, B., & Farenga, S. (1999). Informal science experience, attitudes, future interest in science, and gender of high-ability students: an exploratory study. *School Science and Mathematics, 99*, 431-437.

Knox, K., Moynihan, J., & Markowitz, D. (2003). Evaluation of short-term impact of a high school summer science program on students' perceived knowledge and skills. *Journal of Science Education and Technology, 12*, 471-478.

Koszalka, T. (2002). Technology resources as a mediating factor in career interest development. *Education Technology & Society, 5*(2), 29-38.

Krajcik, J. S.*Research matters - to the science teacher: Microcomputer-based laboratories in the science classroom*. Retrieved October 23, 2004, from www.educ.sfu.ca/narstsite/publications/research/microcomputer.htm.

Laffey, J. M., & Espinosa, L. M. (2003, July). *Appropriation, mastery, and resistance to technology in early childhood preservice teacher education: Case studies.* Paper presented at the IFIP Working Group 3.5 Conference: Young Children and Learning Technologies, UWS Paramatta.

Lawton, M. (1998). *Polled scientists give thumbs-up to reforms*. Retrieved March, 2004, from http://www.edweek.org/we/vol-17/34bayer.h17.

Leroy, F. (2003). *A century of Nobel Prize recipients--chemistry, physics, and medicine*. New York: Marcel Dekker.

Leshner, A. I. (2004). U.S. science dominance is the wrong issue. *Science, 306*, 197.

Lewis, B., & Collins, A. (2001). Interpretive investigation of the science-related career decisions of three African-American college students. *Journal of Research in Science Teaching, 38*, 599-621.

Lowery, L. F. (2003). *Research on hands-on science programs*. Retrieved April 9, 2004, from http://www.fossworks.com/pdfs/HandsOnScienceResearch.pdf.

Malcom, S. (1991). Plugging the pipeline. *Science, 254*(5030), 353.

Marsa, L. (1993). Do high school science competitions predict success? *The Scientist, 7*(8), 21-24.

Mau, W. (2003). Factors that influence persistence in science and engineering career aspirations. *The Career Development Quarterly, 51*(3), 234-243.

McGrayne, S. B. (1993). *Nobel prize women in science*. New York: Carol Publishing Group.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis*. Thousand Oaks, CA: Sage.

Morgan, J. (1996). Building the village - one scientist at a time. *Black Issues in Higher Education, 13*, 22-23.

Morgan, R., & Maneckshana, B. (2002). *AP students in college: An investigation of their course-taking patterns and college majors* (No. SR-2000-09). Princeton, New Jersey: Educational Testing Service.

National Center for Educational Statistics. (2000). *Pursuing excellence: Comparisons of international eighth grade mathematics and science achievement from a U.S. perspective, 1995 and 1999*. Washington, DC: U.S. Government Printing Office.

National Commission on Mathematics and Science Teaching for the 21st Century. (2000). *Before it's too late: A report to the nation*: U.S. Department of Education. Retrieved May 22, 2004 from http://www.ed.gov/americacounts/glenn/toc.html.

National Science Board. (2000). *Science & Engineering Indicators 2000* (No. NSB-00-1). Arlington, VA: National Science Foundation.

National Science Board. (2004). *Science & Engineering Indicators 2004*. Arlington, Va.: National Science Foundation.

National Science Foundation Act of 1950, Public Law 81-507 (Stat. 149).

Nauta, M., Epperson, D., & Waggoner, K. (1999). Perceived causes of success and failure: are women's attributions related to persistence in engineering majors? *Journal of Research in Science Teaching, 36*, 663-676.

O'Brien, V., Martinez-Pons, M., & Kopala, M. (1999). Mathematics self-efficacy, ethnic identity, gender, and career interests related to mathematics and science. *Journal of Educational Research, 92*, 231-235.

O'Neill, K., & Polman, J. (2004). Why educate "little scientists?" Examining the potential of practice-based scientific literacy. *Journal of Research in Science Teaching, 41*, 234-266.

Oral history collection. (Quote by R. S. Young, Used with permission.) Retrieved Feb. 19, 2005, from http://www.chemheritage.org/exhibits/ex-nav2.html.

Paige, R. (2004, October 5). *No time to waste: The vital role of college and university leaders in improving science and mathematics education.* Paper presented at the Invitational Conference on Teacher Preparation and Institutions of Higher Education: Mathematics and Science Content Knowledge, Washington, DC.

Peralta, M. L. (1998). *Testimony on math and science education II: Attracting and graduating scientists and engineers prepared to succeed in academia and industry*. Retrieved May 4, 2004, from http://www.house.gov/science/peralta_04-01.htm.

Phillips, K. A., Chandrasekhar, M., & Barrow, L. (2000, April 30, 2000). *Physical science interests and strong interest inventory profiles of females in a residential summer program.* Paper presented at the National Association for Research in Science Teaching, New Orleans, LA.

Polman, J. L. (2000). Identity development through participation in an informal setting. In B. J. Fishman, & O'Connor-Divelbiss, S. F. (Ed.), *Proceedings of the International Conference of the Learning Sciences* (pp. 340-341). Mahwah, NJ: Lawrence Erlbaum Associates.

Polman, J. L. (2001, April). *Historical learning and identity development on the borders of school.* Paper presented at the Annual Meeting of the American Educational Research Association, Seattle, WA.

Potts, R., & Martinez, I. (1994). Television viewing and children's beliefs about scientists. *Journal of Applied Developmental Psychology, 15*(2), 287-300.

Quita, I. N. (2003). What is a scientist? Perspectives of teachers of color. *Multicultural Education, 11*(1), 29-31.

Ramey-Gassert, L. (1997). Learning science beyond the classroom. *The Elementary School Journal, 97*, 443-450.

Reines, F. (1995). *Frederick Reines - autobiography*. Retrieved May 13, 2004, from http://www.nobel.se/physics/laureates/1995/reines-autobio.html.

Reynolds, A. J. (1991). The middle schooling process: Influences on science and mathematics achievement from the longitudinal study of American youth. *Adolescence, 26*(101), 133-158.

Richmond, G. (1998). Scientific apprenticeship and the role of public schools: General education of a better kind. *Journal of Research in Science Teaching, 35*, 583-587.

Roe, A. (1953). *The making of a scientist*. New York: Dodd, Mead and Company.

Rohrer, J., & Welsch, S. (1998). The Lake Tahoe watershed project; a summer program for female middle school students in math and science. *Roeper Review, 20*(4), 288-290.

Rop, C. (1999). Student perspectives on success in high school chemistry. *Journal of Research in Science Teaching, 36*, 221-237.

Rowsey, R. E. (1997). The effects of teachers and schooling on the vocational choice of university research scientists. *School Science and Mathematics, 97*(1), 20-24.

Ryan, G. W., & Bernard, H. R. (2000). Data management and analysis methods. In N. K. L. Denzin, Y.S. (Ed.), *Handbook of qualitative research* (2nd ed., pp. 769-802). Thousand Oaks, CA: Sage.

Sadler, P., & Tai, R. (2001). Success in introductory college physics: the role of high school preparation. *Science Education, 85*, 111-136.

Sample, I. (2003). *Nobel triumph for super cool physicist*. Retrieved May 13, 2004, from http://education.guardian.co.uk/higher/research/story/0,9865,1058289,00.html.

Sanders, T. (2004, October 5). *No time to waste: The vital role of college and university leaders in improving science and mathematics education.* Paper presented at the Invitational Conference on Teacher Preparation and Institutions of Higher Education: Mathematics and Science Content Knowledge, Washington, DC.

Schibeci, R. A. (1989). Home, school, and peer group influences on student attitudes and achievement in science. *Science Education, 73*, 13-24.

Shank, G. D. (2002). *Qualitative research: A personal skills approach*. Upper Saddle River, NJ: Merrill Prentice Hall.

Shernoff, D., & Hoogstra, L. (2001). Continuing motivation beyond the high school classroom. *New Directions for Child and Adolescent Development, 93*, 73-87.

Silverman, D. (2000). Analyzing talk and text. In N. K. L. Denzin, Y.S. (Ed.), *Handbook of qualitative research* (2nd ed., pp. 821-834). Thousand Oaks, CA: Sage.

Simpson, R. D., & Oliver, J. S. (1985). Attitude toward science and achievement motivation profiles of male and female science students in grades six through ten. *Science Education, 69*, 511-525.

Simpson, R. D., & Oliver, J. S. (1990). A summary of major influences on attitude toward and achievement in science among adolescent students. *Science Education, 74*, 1-18.

Smith, F., & Hausafus, C. (1998). Relationship of family support and ethnic minority students' achievement in science and mathematics. *Journal of Science Education, 82*, 111-125.

Stake, J., & Mares, K. (2001). Science enrichment programs for gifted high school girls and boys; predictors of program impact on science confidence and motivation. *Journal of Research in Science Teaching, 38*, 1065-1088.

Subotnik, R. F., Stone, K. M., & Steiner, C. (2001). Lost generation of elite talent in science. *Journal of Secondary Gifted Education, 13*(1), 33-43.

Talton, H., & Simpson, G. (1986). Relationships of attitudes toward self, family, and school with attitude toward science among adolescents. *Science Education, 70*, 365-374.

Taylor, M., Swetnam, L., & Friot, F. (1999). Women who pursue science education: The teachers they remember, the insights they share. *The Clearing House, 73*(1), 33-36.

Thielen, C. (2002, April/May 2002). 2001 Survey of literature on women in engineering. Retrieved January 22, 2005, from http://www.nmsu.edu/~advprog/SWE%20Spring%2002_Lit%20Survey.pdf

Trusty, J. (2002). Effects of high school course-taking and other variables on choice of science and mathematics college majors. *Journal of Counseling and Development, 80*, 464-474.

U.S. Department of Health and Human Services. (1992). *Curiosity is the key to discovery*: National Institute of Mental Health. Retrieved May 13, 2004 from http://www.swaebr.org/Thank%20You%20Research/Curiosity_is_the_Key.htm.

Von Secker, C., & Lissitz, R. (1999). Estimating the impact of instructional practices on student achievement in science. *Journal of Research in Science Teaching, 36*, 1110-1126.

Weber, R. L. (1980). *Pioneers of science: Nobel prize winners in physics*. London: Institute of Physics.

Weiss, I. R., Pasley, J.D., Smith, P.S., Banilower, E.R., & Heck, D.J. (2003). *Looking inside the classroom: A study of K-12 mathematics and science education in the United States*. Chapel Hill, North Carolina: Horizon Research Inc.

Women in science and engineering. (2004). Retrieved January 22, 2005, from http://echo.gmu.edu/surveys/contributions.php?survey=wscience.

Woolnough, B. E., & Guo, Y. (1997). Factors affecting student choice of career in science and engineering: Parallel studies in Australia, Canada, China, England, Japan, and Portugal. *Research in Science & Technological Education, 15*, 105-122.

APPENDICES

Appendix A: Demographic and Descriptive Information

1. Name[*]
2. Email Address*
3. Age
4. Postgraduate Degree(s)
5. For whom do you (or did you) conduct research?
6. What is (was) your general area of research?
7. In what year did you graduate from high school?
8. In what kind of community or town did you attend high school? (urban, suburban, rural)
9. What kind of high school did you attend? (public, private, parochial, home)
10. About how large was your high school graduating class?
11. What science classes did you take in high school?
12. What kind of grades did you get in high school, in general, and in your science classes?
13. What kind of laboratory facilities did you have in high school?
14. How frequently did you have labs in high school?
15. Did your teachers do a lot of demonstrations in high school?
16. Did your teachers show a lot of audiovisuals in high school?
17. Did your teachers make use of existing technologies in high school?
18. What teaching styles did your teachers use in high school?
19. In what extracurricular science-related activities (e.g., science fairs, science clubs, summer internships), if any, did you participate in high school?
20. In what other extracurricular activities (e.g., sports, music, drama, student government), if any, did you participate in high school?

[*] *(Optional)* This information will not be used in the research paper, nor will it be provided to any other organization or researcher without your written consent. Its sole purpose is to enable the researcher to verify the information, to request clarification, or to ask follow-up questions, if necessary.

(continued)

Descriptive Information (Interview Questions)

1. Describe your high school science experience.
   a. Describe your science teachers' teaching styles/approaches (e.g., lectures, discovery or inquiry based, problems solving, demonstrations). Did you have a favorite? If so, why was it your favorite?
   b. Describe your high school laboratory experiences (e.g., formal write-ups, open-ended, original research, lab manual, computer-based labs, simulations).
   c. Describe your science related extracurricular experiences (e.g., science fairs, science clubs, summer internships).
   d. Describe the technology (including internet and web-site use, videodisks, overhead projections, videocassettes, film, and filmstrips) your science teachers used.
   e. Describe the quality and extent to which you used your high school science textbooks.
   f. Describe your relationships with your individual high school science teachers. Did you have a favorite? If so, why was she/he your favorite?
2. To what extent did your high school science experience influence your decision to pursue a career in science?
   a. What positive factors in your high school science experience, if any, played a significant role in your decision to pursue a career in science?
   b. What negative factors in your high school science experience, if any, made you consider perhaps not pursuing a career in science?
3. If you were to teach science in high school, how would you do it?

Appendix B: Codes and Themes

Non-School-related Influences	red pen
Individual	
Family	
Social	
Elementary School-related Influences	blue pen
Middle and Secondary School-related Influences	
Influence of “Place/time” Programs for MS	orange highlighter
Influence of “Place/time” Programs for HS	orange highlighter
Influence of In-school Science-related Factors	yellow highlighter
Influence of Previous Courses and Success	red highlighter
Influence of Textbooks	yellow highlighter
Influence of Extra- and Co-curricular Experiences	red highlighter
Influence of Technology	yellow highlighter
Influence of Teachers	blue highlighter
Influence of Mentors/Role Models	blue highlighter
Influence of Pedagogical Practices	green highlighter

Appendix C: Follow-up Questions

1. Were either of your parents scientists or science teachers or had a background in science? (If so, what was their field?)

2. How would you describe your family’s SES - socioeconomic status? (e.g., middle class, etc,)

3. Did you have science “toys” (e.g.,, erector set, microscope, chemistry set, insect collection)?

5. Growing up, were you an avid reader, and/or did your parents read to you a lot? If so, what kind of books?

6. Growing up, did you go to museums, national parks, science centers, etc.?

7. Growing up, were there any science “issues” (environment, space, disease) that especially captivated/concerned you?

8. Growing up, did your parent(s) encourage you in your interest in science and pursuit of a career in science?

Appendix D: Selected Nobel Prize Winners in Science and Other Eminent Scientists

1. Marie Curie (1903 *and* 1911) - Father was a high school physics and mathematics teacher, mother was a director of a private school for girls; tutored, earned a girl's high school teaching certificate. "Marie Curie strongly disapproved of the rigid French educational system. Influenced by Pierre's home schooling, she complained about the French lyceum and its long hours, poor lighting and heating, rote instruction, cold lunches, and the lack of physical exercise, art, and laboratory science. Children should think and play more and memorize less, she argued" (McGrayne, p. 123). Marie organized a private cooperative school for 10 children from six professors' families with the professors doing the teaching.
2. Lise Meitner – Father encouraged children to learn science; taught high school; "Luckily, her tutor had a gift for making mathematics and physics extraordinarily stimulating. He even showed his students a real physics laboratory; most tutors taught only from diagrams of experimental apparatus. When Lise saw the lab, she was astonished. Some of the equipment looked very different from what she had imagined" (McGrayne, p. 41).
3. Pierre Curie (1903) - Home-schooled, independent and dreamy, given a tutor at age 14, aptitude for both math and physics, license at 16, father and grandfather were physicians.
4. Carl Ferdinand Braun (1909) - Was one of the few high school teachers who had enthusiasm and energy enough to be active in science despite strenuous teaching responsibilities (Weber, p. 39).

5. Wilhelm Carl Werner Otto Fritz Franz Wien (1911) - Mother's knowledge of history and literature stimulated his lifelong interest in those subjects; was privately tutored, spoke French before he could write German (Weber, p. 42).
6. Heike Kamerlingh Omnes (1913) – "His father … and his mother taught diligence by example and led the family in reading and discussions" (Weber, p. 47).
7. Sir William Henry Bragg (1915) - Born on a farm, lived with an uncle who was a pharmacist; Sir William Lawrence Bragg (1915) was his father; both were concerned for science education and gave lectures for children about beauty and excitement of scientific discovery (Weber, p. 55).
8. Johannes Stark (1919) 1874-1957 - Born on farm.
9. Charles-Edouard Guillaume (1920) - Son of watchmaker, home schooled before high school.
10. Albert Einstein (1921) - Father operated a small electrical and engineering firm (unsuccessful); uncle Jakob aroused his interest with mathematical puzzles.
11. Niels Hendrik David Bohr (1922) - Father was a professor of physiology.
12. Robert Andrews Millikan (1923) - Paid little attention to science in high school; wrote physics textbooks including some for high school.
13. Charles Thomson Rees Wilson (1927) - Father was sheep farmer.
14. Sir Owen Willans Richardson (1929) - Father sold industrial tools; scholarship to Batley Grammar school at age of 12; won contests and a scholarship.
15. Louis-Victor Pierre Raymond, Prince de Broglie (1929) - Brought to science "by philosophy, by generalizations, and by the books of Henri Poincaré" (Weber, p. 92).

16. Erwin Schrödinger (1933) – Was home schooled until 11; father encouraged his interest in nature with a microscope and other equipment.
17. Irène Joliot-Curie (1935) helped surgeons interpret X-rays during WWI as a teenager; Mother was Marie Curie (1903, 1911); taught by mother at home and had a tutor in Polish; "Marie realized that Irène 'resembled her father in her intelligence. She was not so quick as her sister, but one could already see that she had a gift of reasoning power and that she would like science'" p. (McGrayne, 122) at age 10; took a correspondence course in math; attended a private girls' school during her last two years of high school.
18. Sir George Paget Thomson (1937) - Son of physicist Sir Joseph John Thomson (1906).
19. Wolfgang Pauli (1945) - Father was a physician and later a professor of biochemistry.
20. Gerty Radnitz Cori (1947) - Father was a chemist and businessman; privately tutored until ten then attended girls' finishing school; Uncle – a pediatrics professor – encouraged her to attend medical school.
21. Hideki Yukawa (1949) - Father was a professor of geology.
22. Cecil Frank Powell (1950) - "Powell emulated his self-reliant father and his Uncle Horace in liking to do what he could with his own hands." Mother gave dictation to help with spelling; won scholarship at age of 11 (Weber, p. 136).
23. Frits Zernike (1953) - Father wrote math text, mother taught math; "performed endless experiments, enjoyed color photography, and built a miniature observatory equipped with the clockwork of an old record player which enabled him to take pictures of a comet. With his parents he also indulged in solving arduous mathematical problems" (Weber, p. 148).

24. Max Born (1954) - Father was a physician; “Born rated his first lectures as disastrous, but as a teacher he became noted for his clarity, informality, and warm concern for his students at a time when a typical German professor would not even shake hands with a student” (Weber, p. 151).
25. Willis Eugene Lamb, Jr (1955) - Father was a telephone engineer.
26. Polykarp Kusch (1955) - At 15 was a page in the Cleveland Public Library “where he began his voracious, lifelong hobby of reading” (Weber, p. 158).
27. Walter Houser Brattain (1956) - Father was a homesteader, cattle rancher and flour miller.
28. William Shockley (1956) - Farther was a mining engineer.
29. Chen Ning Yang (1957) - Father was eminent mathematician.
30. Ilya Mikhailovich Frank (1958) - Father was a professor of mathematics and mother was physician.
31. Igor Evgenievich Tamm (1958) - Father was an engineer.
32. Owen Chamberlain (1959) - Father was a radiologist.
33. Rudolf Ludwig Mössbauer (1961) - Worked at Rodenstock Optics Factory for two years before college.
34. Lev Davidovich Landau (1962) - Father was an engineer, mother was a physician.
35. Maria Goeppert-Mayer (1963) - Father was a sixth generation university professor (pediatrics); went to the only private girl’s school which prepared girls for university; when it closed due to financial reasons, her teachers continued to instruct her (Weber, p. 190). “He took his daughter on science walks, hunting for quarry fossils and studying forest plants. When she was three and a half years old, she asked for – and he gave – an

accurate description of a half-moon; when she was seven, he made her dark lenses for watching a solar eclipse" (McGrayne, p. 176).

36. J Hans D Jensen (1963) - "A teacher recognized Jensen's ability and secured for him a scholarship…" to a university. (Weber, p. 194).
37. Dorothy Crowfoot Hodgkin (1964) "Her father supervised Egyptian schools and ancient monuments for the British government. Her mother… was a self-taught expert in botany and ancient weaving. She drew the illustrations for the official study *Flora of the Sudan* (McGrayne, p. 226). Moved from one private school to another; "When she was ten, she attended a small class organized to improve the education provided by governesses. Its little chemistry book started off with experiments to grow copper sulfate and alum crystals. Entranced, Dorothy repeated the experiments at home" (p. 226). "In addition to world peace, Dorothy's main interest was chemistry. Her mother was delighted and encouraged her at every turn" (p. 230). Visited a soil chemist, analyzed a mineral, given a surveyor's box full of reagents and minerals, set up a small attic lab, read a book by Nobel Prize winning scientist Bragg.
38. Julian Schwinger (1965) - "was marked at an early age by an intense awareness of physics. Guided by I. I. Rabi, he entered Columbia University, published his first paper at the age of 16, received his BA at 17, his PhD at 21…" (Weber, p. 204).
39. Sin-itiro Tomonaga (1965) - Father was an eminent professor of philosophy.
40. Nikolai Gennadievich Basov (1964) and Hans Albrecht Bethe (1967) and Samuel Chao Chung Ting (1976) and Sir Neville Francis Mott (1977) - Fathers were professors (Weber, p. 209).

41. Luis Walter Alvarez (1968) - Father was a teacher and Mayo Clinic physician who became a medical journalist (Weber, p. 212).
42. Murray Gell-Mann (1969) - Entered Yale at 15, PhD from MIT at 22.
43. Hannes Olof Gösta Alfvén (1970) - Parents were both physicians.
44. Dennis Gabor (1971) - Gather was the director of a coal mining company; "His father interested Dennis in invention through the careers of such men as Thomas Alva Edison and visits to the museum of technology in Budapest. Gabor was fascinated by Abbe's theory of the microscope and Gabriel Lippmann's method of colour photography, which was to influence his work 30 years later (Weber, p. 222).
45. Leon N Cooper (1972) - Graduated from the Bronx High School of Science.
46. Ivar Giaever (1973) - Father was a pharmacist; almost flunked physics.
47. Martin Ryle (1974) - Father was a physician (MD).
48. Aage Niels Bohr (1975) - Father was Niel Bohr (1922); "The remarkable coterie of scientists who were attracted to the Institute became for the Bohr children Uncle Kramers, Uncle Klein, Uncle Nishina, Uncle Heisenberg, Uncle Pauli, etc." (Weber, p. 239).
49. Ben Roy Motelson (1975) - "He has said his childhood home in Chicago was a place where scientific, political and moral issues were freely and vigorously discussed. 'He would have made a great scholar in any field,' said one of Mottelson's colleagures in 1968" (Weber, p. 242).
50. Burton Richter (1976) - "He became interested in science as a boy through the magnifying glass and the microscope, and he developed a chemistry laboratory in the basement of his home. His interest in physics arose through reading and through the high

school's physics laboratory. When about 14, he decided he wanted to go to MIT to study either physics or chemistry" (Weber, p. 245-6).

51. Peter Leonidovich Kapitza (1978) - Son of a general of engineers, sons were engineers.
52. Arno A. Penzias (1978) - attended Brooklyn Technical High School.
53. Robert Woodrow Wilson (1978) - Fascinated as a teenager with electronics.
54. Steven Weinberg (1979) and Sheldon Lee Glashow (1979) - Began their study at the Bronx High School of Science as classmates.
55. Barbara McClintock (1983) - Father was a homeopathic physician; often sent to live with an uncle (sold fish from a horse-drawn wagon) and aunt and "from him learned to repair machinery and to love nature" (McGrayne, p. 148). Tom-boy; attended a small, private school endowed by suffragettes for several years until it collapsed and so she took her college entrance exams a year early.
56. Gertrude B. Elion (1988) - Graduated from high school at 15; "Trudy was a shy bookworm with an insatiable thirst for knowledge…She idolized Louis Pasteur and Marie Curie – 'people who discovered things' – and devoured popular science books like Paul de Kruif's *Microbe Hunters*" (McGrayne, p. 286).

Appendix E: Positive Influence of Parents

1. My mother was a Ph.D. and Chemistry and Physics professor. She taught me all the basics of chemistry and physics that I remember even today after many years. I followed her path, and I got a Ph.D. degree in Biochemistry. By then, I had developed an understanding of how things work in nature and, most importantly, how many unknowns still remained for investigation. (9)
2. I was always interested in anything biological, and my parents encouraged me in a couple of ways: we spent a lot of time on outdoor pursuits, which gave me a lot of opportunities to observe. Also, my mother got pregnant with my little brother when I was 10, and she let me get involved with her pregnancy by answering my questions, letting me take her blood pressure, go to her doctor visits with her and listen to the doctor discuss her pregnancy with her. She gave birth at home with a midwife, so I was also able to attend my brother's birth, which I found fascinating. (15)
3. I received much encouragement from both my parents. Even though I didn't do as well in math and science as I did in the humanities, I realized when I was a teenager that I wanted to be a scientist. My father (who is a scientist) only wanted to make sure that 1) it was what I really wanted and 2) I understood that I would not be rich. Once he was convinced that I knew what I was getting into, he always made a point to introduce me to his female colleagues. Both my parents were supportive of my scholastic achievements and supported me (in many ways including financially) to pursue college and graduate education. (25)

4. I was strongly encouraged to go into engineering by my father who was also an engineer. My younger brother went into engineering also. On long car rides my father loved to make us do math word problems! (30)
5. Well, I wasn't *discouraged*. I was expected to do well in math and pursue some profession by my parents. When I chose geology as a college sophomore, my father was thrilled and immediately arranged for me to spend a day with faculty of the geology department at his university over my winter break. My parents gave me my first hammer that Christmas. (32)
6. My father was a very strong proponent of engineering. Of course, he was an engineer, too. Both my brother and I were equally encouraged to pursue engineering. My father actively involved us in all sorts of activities including ham radio, radio controlled airplanes and other "geeky" math quizzes and questions. By the time I entered college, the only unknown was what discipline of engineering that I would pursue. (48)
7. I was never encouraged or discouraged. I was gifted in math and very inquisitive. My parents treated me equally with my brothers and sisters. Chores that needed to be done needed to be done. It was never considered boy or girl chores, just chores. I did envy my brothers toys that allowed them to build things. I was able to experiment with them when they outgrew them. (51)
8. I was encouraged by my parents and other family members and friends to study engineering. I am fortunate that my father was a Professor and VPI (now Virginia Tech) and the Head of the Mechanical Engineering Department for 30 years. I was always around engineering students, and professors. He encouraged me to study engineering from early childhood. My teachers in high school encouraged me to study math but they (all female) didn't know much about engineering. (54)

9. In elementary school, I heard "girls aren't good at math" which really confused me because I was good at math and really liked it. My mom said that it was nonsense because she was good at math too. She always told me that I could be good at whatever I wanted to do. My dad is a mechanical engineer and a person who answers "how was your day?" in great detail. So, I grew up hearing all about engineering things (and started to understand it after a while). (62)
10. My father encouraged me to pursue a career in engineering. I would help him with projects around the house, and he noticed my mechanical skills. In high school, my male counselor did not really encourage me -- I pursued drafting and electronic classes to help me before attending college. He did however encourage me with my pursuing of the Academic Honors diploma. (64)
11. I was absolutely and positively encouraged. I grew up in a house with extremely supportive parents. They raised me to believe that I could do anything I put my mind to. I was born in 1964, to give you an idea of what era I grew up in. My father had his own business and even though my mother had a college degree, she was a stay at home mom until she started helping my dad with his business. Even though both my parents were incredibly encouraging, they didn't know anything about engineering. That didn't stop them though. They set me up with engineers they knew so that I could talk to them or shadow them. I did both. (70)
12. I was encouraged by my parents. My mother worked as a scientist until I was born (for her generation it was not very acceptable to work after having children) and I think that served as a strong inspiration for me. I think my parents encouraged me to pursue whatever interested me but taught me to appreciate many things from a scientific viewpoint. My father was an

engineer, but he was very knowledgeable about the natural world, teaching me much about plants and animals as a young child. I think my love of the outdoors was inspired by the walks we took together and certainly influenced my career choice in geology. (73)

13. In my family, it wasn't a question of whether or not we would go to college, it was a question of what we'd study and where we'd go. Both my parents had gone to college, but they were the first generation in their families to do so (Mom had been a farm girl in Wisconsin, speaking German until she was in grade school. Dad was a cowboy in Montana). They valued education, but even more, they believed that each person has a responsibility to make the most of their talents. So when I showed aptitudes in math and science, I was encouraged to pursue the development of those aptitudes. Mom and Dad believed that I could be whatever I wanted to be, and it didn't matter what traditional roles might dictate. However, the women in my childhood provided fantastic role models. Mom had been a Woman Marine during WW II, a neighborhood mother had been a Navy nurse, and another had been a flight instructor for the Army Air Corp. These women were all part of normal, lower middle income families. I grew up believing that these women were typical… The only thing that kept me from going into engineering was my own idealism about helping people. I get tired of people saying that the growth in women in the sciences is due to government regulations; it isn't true. Our mothers paved the way for us during WW II, and they gave us their dreams and their belief in our ability to do whatever we wanted to. (75)

14. I grew up in rural South Dakota and was, even as a little girl, curious about biology and what makes living things "tick". In spite of the fact that I am certain that my mother would have preferred a daughter who wore pretty dresses and bows in her hair, neither she, nor my father, ever complained about the numerous dissections I performed, the isopropanol

preserved frog parts, the bugs I put in the freezer, or the plants and leaves I dried in our encyclopedias. (76)

15. I was encouraged by both of my parents to go to college. They stressed that they wanted me and my brother and sisters to have a better life than they did. My father never specified what I should pursue as a college career, however, my mother always spoke well of her elementary and high school teachers and encouraged my sisters and me to pursue a career in education. (78)
16. My family was very encouraging, in part because my dad was an electrical engineer and my grandfather was a biochemist. My brothers and I even got a motorized erector set for Christmas one year -- the ultimate gift for a future engineer! I also had my own little collection of hand tools, starting from when I was 5 or 6 (so I wouldn't swipe my dad's). (79)
17. My parents also encouraged me and sent me to science camps in grade school and an engineering camp for girls in high school. They were always looking for opportunities where I could be exposed to various careers and encouraged me to set my sights high. (81)
18. My parents always encouraged me to do whatever I wanted. They helped foster my fascination with dinosaurs in elementary school (we watched a lot of PBS shows). They often took me camping, to museums, on nature walks and things like that. I was also generally encouraged by my teachers in school and was one of the few female students that did very well in math. (82)
19. My father was a Civil Engineer. When I showed an interest, he was only proud that I wanted to emulate him. My mother wanted me to have a career, period. She did not care whether it was in sciences or otherwise as long as I could be financially independent. (89)

20. I was encouraged by my mother, who was at the time a high school biology teacher. She was born, raised, and college educated in Greece. After coming here (speaking no English) she obtained the graduate degrees which would allow her to be a teacher in the NYC public school system. She was my only source of encouragement to pursue a career in the sciences, until I attended Brooklyn Technical High School, where a science emphasis was (and still is) the rule. (90)
21. My family was always very supportive of anything I was interested in. My father always said that if I didn't love my career, I would be miserable. They definitely did not believe in setting up barriers for their daughters! I was also in a peer group where it was "cool" to be smart. (92)
22. I was encouraged to pursue a career in the sciences. Both of my parents earned bachelor's degrees in chemistry. My father went on to earn a master's and PhD in cellular biology. Later, my father made a career in food science. To me, it was natural to pursue science because I understood what a career in science could look like. I also grew up on a farm. Being around the farm I think was an encouragement toward the sciences. I was also the smartest kid in a very small rural school. That gave me a level of confidence that I probably didn't deserve, but it carried me through some tough beginnings in college. (95)
23. My parents always encouraged me to purse whatever I was interested in. I was actually unaware that girls "didn't do science" because I never felt any of that in my own upbringing. My parents also always supplied whatever toys I was interested in, which included Legos and erector sets. (96)
24. I was encouraged to choose something practical and traditional, hence I got my BS is Science Ed and taught high school for 8 yrs before returning for my Ph.D. in biology. However, my

parents did value education, and we often had open-minded discussions of scientific topics during my childhood that contributed to development of my curiosity and aspirations. (100)

25. My parents also supported me in whatever my interests were - building parade floats and theatrical sets, competing in quiz bowl and math contests, studying Shakespeare, taking over a room for my photo darkroom, editing the year book, teaching myself typing and German in the summer, etc. They didn't make me feel as if any of my interests were inappropriate for girls. (102)
26. My father… expected my sisters and myself to be interested in, and good at accomplishing, scientific inquiries. This mostly took the form of natural history as we interacted with the world around us, aware of biological systems at a myriad of levels. (108)
27. My biggest support came from my father. He told me no matter what my interests, “be the doctor not the nurse, be the pilot not the stewardess.” I have always had an aptitude for math and sciences. He encouraged me to pursue engineering because of larger career opportunities. (121)
28. As a child I had the fortunate opportunity of living in Calgary, Canada. This amazing opportunity opened my eyes and struck my curiosity to explore where such beauty had originated. My family encouraged this curiosity by taking many trips to the mountains, glaciers, and any other natural wonder. The experiences made a permanent impression and I graduated with a degree in Geology. (138)

Appendix F: Positive Influence of Teachers

1. My 7th/8th grade science teacher who actively *encouraged* me by encouraging me to be the lab assistant, grade labs, etc. (109)
2. My math and science teachers encouraged me to compete on academic teams (quiz bowl, math team, junior engineering and technical society team, etc.). My physics teacher especially encouraged me, telling me that he thought I'd be a good physics major. That was really the first time I consciously thought about going into science, and it was some time in my junior year. (102)
3. In high school we had an excellent life sciences programs, and two teachers in particular really influenced my choice of undergraduate major and, ultimately, career (thanks Mr. Landfear and Mr. Carlson!) (92)
4. I was encouraged to pursue a career in the sciences by both my parents and my science teachers from grade school through high school. I had female science teachers throughout my pre-college academic career and was always encouraged by them to participate in science fairs, help out in their classrooms, serve as a "science aide" during my study hall, and strive for excellence in my work. (81)
5. In junior high and high school, my teachers were very supportive. They had high standards, and they challenged all their students to perform. My math teacher got me into a summer math program at SMU in Dallas, my first trip alone away from home. When I decided my senior year to become a nurse instead of going into engineering, my science teachers expressed their disappointment but wished me well in my nursing career (I went back and got my engineering degree in my late 20's, having worked 9 years as a nurse). This wasn't in the

90's, it wasn't in the 80's, it was in 1973. Beginning in junior high, in the late 60's, and through high school, my teachers had all expected me to go into math, science or engineering. This wasn't in a progressive, upper income area; the schools I attended were in lower to lower middle income areas. But all my teachers were very supportive. (75)

6. My chemistry teacher was very supportive and was not concerned about the fact that I was a girl. (He was probably in his 60's at the time.) (71)
7. At school, I was also encouraged by my counselors & teachers, although this was more subtle. I was at the top of my class in high school and I think the subtle encouragement I received from my teachers was probably all they thought I needed and they were probably right. (70)
8. In 3rd grade I was very inquisitive and it started out with me asking questions of my teachers to see if I could stump them. One teacher knew that I was very interested in ballet and gymnastics and she told me that I should study physics because it would help me become a better dancer and gymnast. I believed her and took physics and math when I got to high school. I found that not only did it help me understand why I had to lean backwards when vaulting, and why rising up higher on my toes helped me to do triple pirouettes… My chemistry and physics teachers encouraged me to study whatever I wanted to. (66)
9. Other than that, I wasn't particularly encouraged or discouraged about science until junior year of high school. Then, a teacher asked me "What are you going to study in college? Computer what? You're doing something with computers, of course." That was the first that I gave thought to studying computer science. This same teacher also gave me many opportunities to learn computer science material that wasn't offered in the high school's courses. (63)

10. Yes. Starting with a 5th grade math aptitude test that showed I was at a 9th grade level, I was encouraged to do well in math especially. From grades 7-12, I was in a special math track, called Unified Math. When my high school math teacher asked me what I planned to major in at college, I told him math. He encouraged me to start with engineering. So, I went home and looked up engineering in the World Book Encyclopedia! (44)
11. My high school science teacher was a big influence on my life. She showed me that because I am a woman I can do anything a man can do. She also showed me I can often do it better. (20)
12. I did have a female biology teacher in the 5th grade that was a lasting impression - I wanted to know everything she did! (8)
13. I went to my high school guidance counselor (male) after taking chemistry my junior year. I told him that I really liked chemistry and I wanted a career related to it, he gave me brochures on two year clinical chemistry programs. I took them to my chemistry teacher (female)and asked for help in getting scholarships. She threw them in the trash and said I did not want to waste my intelligence on a anything less than a BS. Later, she helped me get a scholarship when my guidance counselor told me I should go to the local college. I now have a Ph.D. in Biochemistry, and I owe it to her influence. (6)
14. I also had a very supportive high school chemistry teacher who strongly encouraged and supported girls to pursue careers in science. He actually took four of us to a week-long summer program on women and engineering. All four of us became scientists or engineers. (3)

Appendix G: Negative Influences of Various Individuals

1. When I entered high school I was interested in becoming a marine biologist. I was told by my entrance counselor that "Girls don't do science". This deterred me for many years, but I have since completed my Ph.D. in Wildlife Biology with an emphasis on marine mammal diving physiology. (5)
2. In grade school, my fifth grade teacher called me in after class to suggest that I might not want to answer questions so much or show how smart I was because the boys might not like me. I am glad to have been a part of changing this notion, and I am glad that I had parents who did not distinguish between male and female in expectations of intelligence and achievement. My father [name] was unusual for his time and upbringing. (6)
3. At the time and place (Switzerland) where I went to school girls were prohibited to take science courses or mathematics beyond arithmetic and geometry. They were to take cooking, house cleaning, sowing and sock mending classes. Smart girls were definitely not popular and it was best to play dumb and not do too well on exams, or incur the wrath of boys and other girls. Teachers sent me to a shrink at age 12 when I told them I wanted to become a doctor - me? a girl from a poor large family. One teacher told me to be realistic and stay within my milieu. No one in my family had ever gone on to higher education. The shrink asked me to interpret Rorschach ink blots, which then would tell her what should become of me - she decided I was cut out to be a seamstress. The choices were seamstress, sales lady, or housekeeper. (12)
4. Early on, my teachers decided that I did not like math, since I hated doing ten thousand problems that were all addition, subtraction, multiplication, and division. As a result, the

school told my parents I couldn't take algebra in 8th grade because my math grades were poor in earlier grades. My parents complained, I took algebra, and, needless to say, I LOVED it and got great grades. My 8th grade algebra teacher was a woman; it was very unusual to have a female math/science teacher - except for lower math and biology - in my rural school district. Miss R_ encouraged me a great deal. I don't remember being encouraged as a high school student, except by my parents. I had two science teachers who were any good (physics and chemistry II; there was no AP in my high school). My general feeling throughout school was that most teachers don't like demanding students. (At the levels they are paid, I understand why!!!) However, it really squelched my respect for them and my enthusiasm for school in general. I remember a specific example of how as a smart girl, I assumed that boys shouldn't be interested in me. (19)

5. I wanted to be a veterinarian and was encouraged by my family. However when I asked our "family veterinarian" about pursuing a career in the field he pretty much told me to forget it. It was too hard and I would never make it. I think I was about 12 at the time. That discouraged me so much that I did not go back to pursuing my dream until after my first year of college. (21)
6. Although I had excellent math and science teachers, the curriculum at my school was strongly biased towards languages and literature and I found myself boxed in taking 2 languages and no science as a sophomore in high school because I would not receive credit for my 1st year of Latin if I did not take the second. Also, only 3 years of mathematics (no calculus) was offered at my school. In retrospect, I am glad I had the Latin, but what I wanted was both. (24)

7. Some of my science teachers were very encouraging, and others were very discouraging. I dealt with many sexist comments and put-downs throughout my science classes from middle school on up. (28)
8. I blew the curve for Chem II in high school, took Bio I and II in H.S., placed out of a majors bio course in college, and not once did someone say, "Have you considered going into science?" I was encouraged to be a writer or to go into law. (52)
9. I wasn't discouraged but I don't think I was encouraged. I absolutely loved math in high school and had a strong affinity for the physical sciences but I lacked a good guidance counselor (or personal drive) to help me in choosing a career path. I enrolled in college with the intent of pursuing a career in engineering (following my father's footsteps, mother is a nurse and I don't do blood) but had a nagging math desire. I was told I could pursue a career in teaching if I liked math - not for me. (55)
10. When it came time for me to think about college and a major, I expressed my interest in becoming a doctor to my high school guidance counselor. He smiled and suggested that I consider nursing instead. This was 1968, in a very small Midwestern town and high school. (59)
11. When I made it to high school, my guidance counselor, a woman in her late 50s or early 60s also encouraged me to get a degree in education and teach. That was the advice that she gave to all of her girls who did well in high school. Frankly, coming from a very small town in South Carolina, and graduating in 1976, most adults were still in the mode of traditional roles for men and women, and were like minded about traditional career choices. I believe they didn't encourage me to be anything else other than a nurse or a teacher due to ignorance, not malice. (78)

12. But my high school guidance counselor could never get past the teacher-or-nurse stereotyping for his "smart girls." He strongly recommended that I attend a women's liberal-arts college in NY, and when I asked him why, he said "That's where my girlfriend went and she liked it a lot. The campus is really pretty and rural, and yet you're only a short train ride from New York City." Sheeesh! Fortunately, even as a high school junior I knew that my guidance counselor was NOT someone whose opinions were worth much. Unfortunately, not all young women are as self-confident (or maybe I should say headstrong!) as I was. I have no doubt that many girls are discouraged from even considering traditionally male fields of endeavor, by their families or by their high schools or even by their own circle of friends. (79)
13. My parents consistently encouraged my brother and me to do whatever we wished with our lives. As it turned out, I went the academic route to a PhD in engineering and my brother never attended college at all. My parents also passed on their belief that a woman's opinions are less important than a man's, whatever the question. When it came down to particulars, their opinions on what was/was not appropriate for me to do pushed aside their high-sounding philosophy... I remember my mother telling me that girls tend to do more poorly in math than boys, and better in language and grammar. It was obvious to me that, in our family, the man was in the controlling position. The woman was supposed to come in second to him, and the children even farther back. When I decided to attend an engineering school after high school, though, they supported me financially and emotionally as well as they were able. (90)
14. During elementary and junior high school, there were no teachers who really emphasized science. One math teacher told me I'm just not good at math, rather than scrutinizing the

situation more closely and realizing what was really hampering my performance at the time. (99)

15. I was encouraged by my parents mostly (they both have scientific advanced degrees). I was discouraged by several high school teachers and encouraged by some of my college professors. I do have the feeling that I wouldn't have studied physics if I hadn't been very stubborn. (107)
16. Yes, mostly by teachers in elementary school and high school. (I knew at 10 that I wanted to be an astronomer.) My parents weren't that impressed - they thought it would pass, like my desires to be a ballerina, a nun, etc... (110)
17. On the yes side: - My mother saw that I was interested in math and science and encouraged me to learn as much as possible - I had a great chemistry teacher in high school who encouraged me On the no side: - I had a guidance counselor in high school who said I could not take advanced chemistry in my last year because "my mind was like a teacup and, even though I had done well in the past, the teacup was filling up and I did not have enough room there for more chemistry - only enough room in there for more biology." Luckily, my mother changed my guidance counselor the next day. (120)
18. I was not encouraged to pursue a career in science. It is very strange because I was always encouraged to study science and read about science as a child by my parents and then in school they always favored my studies in science over math or English however it was never discussed that I could have a career in science. .I would say it got worse as I got older in HS and my teachers saw that I had an extreme curiosity. They thought I should be completely accepting of what was taught and I was discouraged from asking question. "Why can't you

just study quietly like the boys?" I was asked. I want to add in HS I was the only student to take all 4 AP courses for 4 years in my class. I was curious about everything!! (133)

Appendix H: Influence of Special Science-related Experiences

1. I joined the science club in high school, was good in my science classes but was not encouraged to pursue it. It was for "boys". Also, as a Mexican American girl, my schooling and resources at the school was very poor. My school district was the reason the education system in Texas was declared unconstitutional. There is even a chapter about my schools in Jonathan Kozol's book *Savage Inequalities*. However, I spent lots of time outdoors and walked to the bookmobile and studied insects on my own… I had one female biology teacher that gave me an assignment that encouraged my study of insects. She assigned making an insect collection of ten bugs and I gave her 100 insects. I was 14 years old at the time. But that was the extent of female support. (4)
2. As a good student I was encouraged to participate in academic competitions for math, writing, history, and science fairs. Perhaps I was encouraged even more BECAUSE I am female. Eventually, it was my high school drafting teacher that introduced me to engineering and helped give me the confidence to pursue an engineering career. (36)
3. I was always good at math and science and wanted to go into engineering from the 6th grade. Encouragement mostly came in the form of a "lack of discouragement". Nobody ever told me I could not do it so I never questioned whether I should. My mother is a pharmacist and my father is an engineer so my family was very supportive of scientific pursuits. Additionally, I participated in an Olympics of the Mind competition in the 6th grade on a team of all girls building balsa wood bridges. We won the State competition and participated at the national level. It was definitely a positive environment! (77)

4. I was encouraged to pursue a career in the health care industry. Later in high school I discovered Chemistry and was encouraged to pursue a degree in Pharmacy. I took 4 years of math and science in high school. This encouragement came from my parents. My chemistry instructor in high school was also very encouraging. There was a Medical Science Club at my high school too. The most participants were girls. (83)
5. The public school system in South Dakota did not directly encourage young women to pursue careers in sciences or applied sciences, though they also did not choose to block participation in Math and Science competitions by the time I was involved. A Math competition actually was the source of a scholarship that assisted my first year of college. My parents were supportive of all challenging intellectual pursuits for all their children. It was a source of much pride for them when I took advanced classes and placed high in "technical" competitions. Others in the family, were not so agreeable, and felt that it was a terrible waste to send me to an engineering school, even if I was mechanically and math inclined. (101)

Appendix I: Influence of Math, Reading, Computers, and Rigorous Courses

1. Don't let the low stats let you believe that women don't have a presence in the sciences. What is typically shown (statistically) is the lack of women pursuing a career in the geosciences (other sciences have a much greater % of women). Also, *you can do math*!!! You do it everyday!! Do not ever think that it is outside of your ability. Math is the key to any scientific success (on any level). Whether you master more simplistic math (pre-algebra) or take it to higher levels...vector calculus and beyond...thinking quantitatively is within your grasp. If at first you don't succeed, get a tutor and make it happen. Find a mentor or let yourself be found! You can go your education alone, but why should you. Support is everywhere. (138)
2. Both of my parents did not finish college and my Grandmother was self-educated. She did however work as a nurse and owned and operated a private hospital in the rural area until the state finally built a public hospital. I was more into technology and art as a child so really how much support could I get. My grandmother did buy me every electronic gadget and my first PC back in the day of Vic 20's. (129)
3. Both of my parents are/were scientists (my father is deceased), so entering science seemed not only natural, but almost expected. I was always encouraged to excel at academics and pursue whatever interests I entertained. My brother and I were instilled with a love for reading at a very early age - my father read to us every night, and took us to the library every other week. (128)
4. No, I can recall very few science roll models in middle school, except for one math teach who threw mad balls at boys, she was very cool. In high school I had a great math teacher

who encouraged me to take more math, in college my first math class was taught by a women, who was very helpful. I think having women professor and teachers helped me feel comfortable with math. (122)

5. Become absolutely fluent in as many types of math as possible. Read everything you can get your hands on, and don't worry about not understanding everything initially. Even Nobel Laureates can explain only an infinitesimally small part of the universe. Surround yourself with advocates. (99)
6. Both my parents and my high school encouraged me to pursue a degree in the sciences. I was a very good science and math student and at a small Upper Michigan school, was given the opportunity to be the first student to take calculus as I had a brother taking engineering in college and we used the freshman calculus book from that school. (71)
7. I was always encouraged to pursue a career in the sciences/applied sciences when I was a girl. I had a neighbor that was a science teacher and my father is an engineer and they always told me that I could do anything I put my mind to. Since I was interested in science and math throughout my schooling, I was encouraged to pursue such things at a higher level. (50)
8. Well, my experience started in High School when I joined a Computer Club and was told I would probably end up in Engineering by the President of our Computer Club. I kind of scoffed at that, because I didn't like Math. But eventually I did get deeper into Math because I continued on. Then I was supported very much by NASA Engineers to continue because of my interest and hard work. (46)
9. I was encouraged to be an electrical engineer like my father who sometimes helped with my homework. My mother was not scientifically inclined, but she always said that we could achieve anything if we tried hard enough. That wasn't surprising since she was one of the

first woman executives at Sears in the 1950s. I became interested mathematics. Then, in 1973, my high school purchased one of the first less-expensive computers available. I found Basic programming interesting but didn't like paper storage tapes. Most teachers were very encouraging to all students. However, at that time, there were few women teaching the sciences/ applied sciences. (41)

10. I was encouraged to continue taking math & science courses. Based on a test taken in 6th grade, I was tracked into algebra in 7th grade. My group was a year or two ahead of other students, and we completed a full year of calculus while still in high school. I was not encouraged to pursue any specific career until I received a brochure from Purdue's Women in Engineering program. This was when I first considered engineering (having ruled out medicine after taking advanced biology in high school). (39)
11. I had great teachers in both elementary and high school who encouraged both male and female students to do what they loved. I excelled in math and sciences, and I took "honors" classes, so the instructors led me to believe that I could and would do well in whatever I chose to do. Since this was all at 2 public schools in El Paso, Texas, I feel very blessed. I know this was not the case for everyone. (34)
12. I was encouraged by both of my parents to go to college, which was unusual for our working-class town (but my parents were pretty unusual among their peers.) I was praised for my math skills by my parents and my math teacher, and my mother was the one who suggested I become an engineer. She didn't know what it was but she knew it took math skills, also, she had seen two of her brothers move out of the blue collar world through good jobs in engineering. My mom started encouraging me to think of engineering when I was a junior in

high school; before that, it was just general encouragement to go to college and get a good job that wasn't blue collar work. (33)

13. At home, I was strongly encouraged. My mother has a bachelor's degree in Chemistry and my father is a physics professor. At school, however, it was a different story. I grew up in a rural area of Pennsylvania (Berks County). I was placed in a gifted program and I remember a game we played in about 5th grade called "predator prey". It was a population biology game and I enjoyed it. I also had a fifth grade teacher (male) who had devised an astronomy game. Students could advance up the "ranks" by passing certain (voluntary) tests on astronomy. I think I was the only girl to make it to the highest rank. Competition was fierce and the advance of one of us drove the others to study and try to advance too. (19)
14. My home environment was often chaotic, but my parents both love classical music, and are both great readers, so I took to those appetites from a young age, too. I believe the music and reading helped my mind develop in spite of the difficulties we had at home sometimes. As I got older, the encouragement I needed began to falter, as I had some unusual circumstances when I first applied for college. After a few failed attempts, my parents dropped the subject because I was needed at home to help my mother (she has a disability) with my brother and running the household. I did all the cooking, cleaning, and caring for my brother for much of my adolescence. Thank goodness I became friends with an older couple who both had academic backgrounds. They immediately began to talk to my parents about the importance of me going to college, and because of their encouragement, I did go. (15)

Appendix J: Influence of Small Groups and Hands-on Experiences

1. My dad is a physicist and my mom a psychologist and so I received subtle encouragement in the interest they showed in the sciences. As my interest grew and I took more classes in these areas, I found more and more males in the classes. Luckily, the girls that were in the science track, stuck together and encouraged one another. (7)
2. In high school there was a group of top ten students in the class that I think maybe half of us went into science or computer science. We were close enough that science didn't seem too radical of a choice. I don't know that we directly encouraged each other though. The same was probably true in undergraduate school. (10)
3. Having a support group has always been very important. This began in high school when I took advance math and science classes and continued through college and grad school. There are colleagues today whom I seek out for advice or just to listen, upon occasion. (27)
4. The mere fact that I received support from women in grammar and high school to go on to college was important, even if they did not encourage me to pursue science or engineering. Second, when I was in college and graduate school and in the work place, it was important to have other women to talk to who have been through what I was experiencing and who could share their experiences. Often times, when the going gets rough, we think that we are the only ones who have been in this situation. It is good to know that you are not alone. (78)
5. I think the fact that I went to very small schools helped in this regard. In grade school (Middlefield school district No. 2) we were the biggest class at 7 students. In high school, at the 'big' central school (Milford central school), my class graduated 22 students. There isn't a

lot of room for discouragement amongst the few, nor is there any emphasis on 'normality' since individuality is more obvious. (108)

6. While my parents weren't indifferent to what I (and my younger sister who is an astrophysicist) chose to do or be interested in they were supportive of anything we chose. My mom is very analytical and mechanically oriented, and that rubbed off, and my dad loves science and new technology, and his interest rubbed off as well. (16)
7. My father is a mechanical engineer, I am a civil engineer. My father always taught me how to use tools and fix things. All my grades were expected to be good, not just English, Social Studies, etc. My mother expected me to have a career in some profession (not firefighting. She thought girls wouldn't be strong enough). In HS, a couple boys said I could not go to RPI as it was a boy's school. That's where I went. (40)
8. As a girl, I grew up on a ranch. My oldest brother was 6 years younger than I and there was much work to be done, some required mechanical training and logical problem training. I wanted to be a vet, which was greatly encouraged. (109).
9. No, I was not encouraged, however, I was not discouraged. Pursuing a career in engineering is a result of my interest and enjoyment of higher math. One thing led to another. I chose engineering, and particularly civil engineering based on curriculum requirements (I knew I could do well with the course work), and my love of outdoors. Construction related to civil engineering would lead me to an occupation where I could spend time out of doors. (114)
10. My school was happy for me to pursue academic sciences (physics and chemistry) but when I put down technical drawing and auto maintenance as options I was forced to drop them in favor of Latin. My family's initial reaction to my desire to be an engineer was disbelief, but once they'd got over the shock their main concern was that I didn't drop academic subjects in

favor of technical ones. They were happy to support my decision to do an engineering degree so long as I went to a university, not to a technical college. (119)

Appendix K: Demographics of Interviewed Scientists

(The “Code” is the initials of the scientist. The tables are alphabetized by the last name. When two scientists have the same initials, a number follows in order to differentiate between them.)

Code	Sex	Age	Race	SES	Encourage	Parents' Jobs
TA	M	54	W	m	econ (job)	x (non sci)
MA	M	46	W		parents (p)	farmer
JB	F	52	W			
BB	M	45	W	lm	mom (m)	x
RB	M	37	AfA	lm	p	m - bio tchr
RC	M	49	W	um	p	d - physician
DC	M	33	W	m		d-psych,u-elec eng
YF	F	39	AsA	m	p	d - physicist/prof
GG1	M	46	W			hgwy const
GG2	M	48	W			m-nurse
MH	F	46	W	m	m	d - construction
HH	M	63	W	m	p	d-BS chem
JI	F	42	NaA	m	dad (d)	d-math m elem tchr
DK	M	51	W	lm	no	d - auto mech
BL	M	39	W	m	econ	d - LANL non-sci
EM	M	42	W	m	p	m-tchr, d-forester
BM	M	33	AfA	l	p,gm	
DN	F	32	W	um	p	d - phys doc/prof
JP	F	51	W	lm	p	x
EP1	M	46	W	um	p	d-physician
MP	M	43	W	m	p,a,s	m-env. rel. firm
EP2	F	38	AfA	m	m	x
CR	M	39	W	m	no	d-BS chem eng
GR	M	49	W	m	econ	d-optics eng
FR	M	46	His	um	p	d-inorg chem
TR	M	51	W	m	1p of 2	x
WR	M	46	AfA	l	m,gm	x
JS	F	43	W	m	no	
KT	M	57	W	l	p (q)	x
DT	M	51	W	m	p	m - some nursing
TW	M	39	W			m-nurse d-eng
AW	F	41	W	lm	p	x

Appendix K: Demographics of Interviewed Scientists (continued)

Code	School	Field
TA	Colo Sch Mines	eng physics
MA	Iowa State	soil science
JB	Idaho State	env remediation
BB	U of Idaho	analytical chem
RB	SIU-Carbondale	molecular bio, biochem
RC	Virginia Tech	env microbiology
DC	U of Idaho	microbiology
YF	Stanford	civil eng/env chem
GG1	U of Idaho	surface chem/forensics
GG2	U of Nebraska	analytical chem
MH	Utah State	soil microbiology
HH	Cal Tech	organic chemistry
JI	Univ Arizona	surface chemistry
DK	U of Minn	material sci
BL	Idaho State	biotech
EM	NMIMT	hydrology
BM	Univ Michigan	medicine
DN	Univ of Arizona	genetics/biotechnology
JP	Vir Tech	physics
EP1	Montana S	inorganic and polymer chem
MP	NMIMT	earth science
EP2	Barry (Miami)	bio/polymers
CR	Texas Tech	environmental toxicology
GR	Stanford	civil eng/aquatic chem
FR	Univ Cal Riverside	molecular bio, biotechnology
TR	Univ Arizona	optical sciences
WR	Wash U Med/Yale	medicine
JS	Univ Arkansas	physical inorganic chemistry
KT	UCLA	physics
DT	Johns Hopkins	biochemical toxicology
TW	Univ Arizona	optical sciences
AW	Unv Colorado	pharmocology/MB

Appendix K: Demographics of Interviewed Scientists (continued)

Code	High School	type	class size	sci courses *	grades
TA	urban Colo	catholic	200	p,c	a's,b's
MA	rural Iowa	public	100	c p b	a's, b's
JB	rural Idaho	catholic	50	p b c	a's
BB	rural Nebraska	public	42	b p es	b's
RB	urban Alabama	public	450	b,c,honb,honp	a's,b's
RC	urban Oregon	public	220	p c b gs no AP	10%
DC	suburban NY	catholic	300	p b c no AP	25%
YF	suburban NY	public	300	Apb Apc App	1%
GG1	rural Colorado	public	50	gs	b's
GG2	suburban Ohio	public	150	c p	a's,b's
MH	suburban Nevada	public	500	b c p Apc Apb	a's
HH	urban Illinois	public	303	c p	a's
JI	suburban NM	public	242	b c no AP	1st
DK	rural Minn	public	110	c,p,b	a's,b's
BL	suburban Idaho	public	300	b, a&p, c p	a's,b's
EM	rural Minn	public	300	b p c (adv)	a's,b's
BM	urban Indiana	magnate	700	b,c,p,lab,research	a's,few b's,6th
DN	urban Idaho	public	450	Apb p c	a's
JP	rural Tenn	public	100	b c p	a,s
EP1	rural Montana	public	350	b c p no AP	~3.3
MP	suburban Mass	public	large	b p c	a's, b's
EP2	urban Florida	public	400	b,c	a's,b's
CR	suburban Idaho	public	299	b p	d's
GR	suburban Calif	public	400	b c p Apc	1%
FR	rural Calif	catholic	69	c b advb anat p no AP	3.94
TR	suburban Calif	public	650	p b/c no AP	25%
WR	urban Memphis	public	300	b,Apb,c,Apc,p	4%
JS	rural(2) urban PA	private	1	b,c,p	a's
KT	suburban Calif	public	400	p c b	a's sci,b's&c's
DT	suburban Minn	public	175	b c p no AP	3.8
TW	suburban Mass	public	600	b c APp APc	a's,b's
AW	suburban Colo	public	650	c p b a&p	a's

(* b-biology, c-chemistry, p-physics, A-advanced, AP-advanced placement)

Appendix K: Demographics of Interviewed Scientists (continued)

Code	High School	type	lab facilities	freq of labs	demos
TA	urban Colo	catholic	separate, well equipped	?	yes
MA	rural Iowa	public	separate	1/wk	yes
JB	rural Idaho	catholic	excellent	2/wk	interactive
BB	rural Nebraska	public	combined	1/wk	no
RB	urban Alabama	public	combined, well equipped	1/wk or 2	yes
RC	urban Oregon	public	modern	1/wk or 2	yes
DC	suburban NY	catholic			
YF	suburban NY	public			
GG1	rural Colorado	public	combined	?	?
GG2	suburban Iowa	public	separate	1/wk	no
MH	suburban Nevada	public	separate	2/wk	avg
HH	urban Illinois	public	standard	yes	no
JI	suburban NM	public			
DK	rural Minn	public	countertops	1-3/wk	few
BL	suburban Idaho	public	regular	1/wk	yes
EM	rural Minn	public	separate	1/wk	no
BM	urban Indiana	magnate	excellent		
DN	urban Idaho	public	minimal	1-3/wk	yes
JP	rural Tenn	public	average	1/wk or month	yes
EP1	rural Montana	public	old but adequate	daily	seldom
MP	suburban Mass	public	separate	1/wk	?
EP2	urban Florida	public	combined	?	chem
CR	suburban Idaho	public	standard	2/wk	yes
GR	suburban Calif	public			
FR	rural Calif	catholic	decent	2/wk	
TR	suburban Calif	public			
WR	urban Memphis	public	2nd rate	3/wk	chem
JS	rural(2) urban PA	private	regular	1/wk	yes
KT	suburban Calif	public	limited	1/wk	no
DT	suburban Minn	public	typical	few	yes
TW	suburban Mass	public	combined	whenever	yes
AW	suburban Colo	public	good	2/wk	yes

(combined – classroom and lab space combined; ? – did not know)

Appendix K: Demographics of Interviewed Scientists (continued)

Code	**Encourage***	**reading** (p-parents)	**science-related issues**
TA	econ	yes det	moon,abomb drills,beat Russians
MA	p	yes	
JB			
BB	m	Hardy Boys,Boys Life	env. Movement TV specials
RB	p	very,old bio, p	
RC	p	some scifi	end species,invading species,clear cut logging
DC		p,scifi,adv,stories	
YF	p	clas,adv,fan,scific	env, health
GG1			
GG2			env, ecology
MH	m	m-hist	env - water, deforestation; near Sierra Nevadas
HH	med	adv hist	none
JI	d	p,Nancy Drew,fic	env
DK	no	some scifi	space exploration
BL	econ	no	
EM	p	m,class comics	
BM	p,gm	no	disease (asthma as child)
DN	p	no	none
JP	p	yes	space
EP1	p	yes, Char Web	lived near infectious disease lab - issues in home
MP	p,a,s	Tom Swift	env,space
EP2	m	no	
CR	no	no	
GR	econ	fant,mys	space, then science
FR	p	yes	space, near Edwards AFB
TR	1p of 2	scifi, comics	mission to moon, arche finds, controversies
WR	m,gm	scifi, gm	
JS	no	med	neuroscience
KT	p (q)	yes (g)	space missions
DT	p	adv	env, pollution, food additives
TW		adv hist	
AW	p	dad,yes,scifi,adv	recycling,gen diseases and cf (sick as child)

(* m-mom, d-dad, p-parents, a-aunt, s-sister, gm-grandmother, econ-goal was a job)

Appendix L: Page Numbers of Scientists' Quotes

Code	Page numbers of quotes
TA	103,112,122,130,139,154,159
MA	98
JB	122,137,155,165,170,185
BB	126
RB	112,116,127,138,191
RC	114,118,123,125(2),127,150,168,171
DC	97,118(2),141,144,156(2),164(2),167,175,177,179,186
YF	121,177
GG1	
GG2	105,183
MH	104,107,117,123,124,151,168,181,183
HH	120,148,152
JI	115,121,128,151,153,154,161,165,184,187
DK	99
BL	107,156,171,185
EM	112,159,172
BM	157
DN	97,127,134(2),136,144,152,159,171,181
JP	98,102,104,107,117,158(2),188
EP1	135,137,176
MP	99,109,140,186
EP2	106,119,127,190,192(2)
CR	109,110
GR	178
FR	101,108,109,118,132,151,165,178,180,185,189
TR	102,127,149,155,170,183,186
WR	102,108,111,119,126,131,146,179,181,190
JS	135
KT	100,106,114,150,152(2),163,176
DT	115,120,129,147,161,166,174,176
TW	110,142,143,153,162
AW	122,131,136,138,140,146,157,172,174,187

Appendix M: Positive Teacher Characteristics by Scientist - Passion for Teaching and Science

Contagious – confident, dynamic, energetic, enthusiastic, excited, inspirational, interesting, motivate, passionate
Content – apply, come alive, competent, connect, engaging, excellent, explained, fun, gifted, integrate, knowledgeable, mastery, prepared, relate, relevant, tangible
Challenge – captivate, demanding, driven, engaged, intrigue, organized, pushed, stimulate
Character – funny, goofy, kooky, laid back, lit up, nerd, nutty, sense of humor, wacky, wild

Code	Contagious	Content	Challenge	Character
TA		*	*	*
MA	*	*	*	*
JB	*	*	*	*
BB	*	*	*	
RB	*	*		
RC	*		*	
DC	*	*	*	*
YF	*			
GG1		*		
GG2				
MH		*		
HH	*	*	*	
JI	*	*	*	
DK	*		*	
BL		*	*	*
EM	*		*	
BM				
DN	*	*	*	*
JP	*	*		
EP1	*	*	*	
MP	*	*	*	*
EP2	*		*	
CR		*		
GR	*	*	*	
FR	*	*	*	*
TR	*	*		*
WR	*	*		
JS	*	*		
KT	*	*	*	
DT		*	*	
TW		*	*	*
AW	*	*		

Appendix M (cont): Positive Teacher Characteristics by Scientist – Compassion for Students

Caring – cultivate, dedicated, discerning, friendly, explained, helpful, gracious, interested in me, nurturing, personable, relational, safe, went out of his/her way
Respect – reasonable; (frequently implied but not specifically stated)
Discipline – classroom management; (mentioned only when there was a need for it)
Encouragement – had potential; (frequently implied but not specifically stated)
Involvement – accessible, could talk to

Code	Caring	Respect	Discipline	Encouragement	Involvement
TA					
MA	*	*	*		
JB	*			*	
BB				*	
RB	*				
RC	*				
DC			*		
YF	*	*		*	*
GG1					
GG2	*			*	*
MH				*	
HH	*				
JI		*		*	*
DK	*				
BL	*				
EM		*	*		
BM	*				
DN		*			
JP				*	
EP1	*			*	
MP					
EP2	*				
CR			*	*	
GR					
FR					
TR	*		*		*
WR	*		*		
JS					
KT	*	*	*	*	*
DT		*			
TW	*				
AW	*			*	

Appendix N: Informed Consent Form

College of Education

8001 Natural Bridge Road
St. Louis, Missouri 63121-4499
Telephone: 314-516-5375
Fax: 314-516-7025

Informed Consent for Participation in Research Activities

How High School Science-related Experiences Influenced Career Persistence

Participant ______________________________________HSC Approval Number ______________

Principal Investigator Andrew D. Shaw PI's Phone Number 636-530-9560

Why am I being asked to participate?

You are invited to participate in a research study about how high school science related experiences affected practicing scientists in their pursuit of their career conducted by Andrew Shaw at the University of Missouri-St. You have been asked to participate in the research because you are or have been a scientist and may be eligible to participate. We ask that you read this form and ask any questions you may have before agreeing to be in the research. Your participation in this research is voluntary. Your decision whether to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship.

What is the purpose of this research?

The purpose of this research is to identify some of the high school science-related experiences that influenced practicing scientists in their career choice.

What procedures are involved?

If you agree to participate in this research, you can expect:

- To be asked to complete a single page questionnaire requesting from you general demographic data about you and your high school experience. Then you will be provided with a copy of 8 questions for you to think about before a subsequent interview. At your convenience, this interview will be scheduled and your responses, along with your responses to any follow-up questions will be audio-recorded. You may be contacted in the weeks that follow for some clarification or further comments as additional questions or avenues of inquiry may arise from other interviews.

- Completion of the questionnaire should take about half an hour. The interview will last between 45 and 90 minutes, depending on the length of your responses and the number of follow-up questions. Post-interview questions, if any, should last no more than 5-10 minutes.

  Less than 50 scientists from around the country will be involved in this study.

What are the potential risks and discomforts?

There are certain risks and discomforts that may be associated with this research. They include any inconvenience to you because of the time expended in answering the questions and any discomfort that is sometimes associated with the recall of unpleasant memories, if any, from this time in your life. Your name and any identifying characteristics (e.g., where you attended high school or your present position) will not be used in any written or verbal presentation.

Are there benefits to taking part in the research?

Your participation in this study may help to improve science education at the high school level through the identification of "best practices" and other science related programs and experiences that may encourage pre-college students to pursue a career in science.

What other options are there?

If you prefer, you may type written responses to your interview questions in lieu of an interview and mail or email them to the researcher. You may also record your verbal responses in private and send the audio-tape or CD to the researcher.

Will I be told about new information that may affect my decision to participate?

I do not anticipate any changes that would affect your decision. However, during the course of the study you will be informed of any significant new findings or new alternatives to participation that might cause you to change your mind about continuing in the study. If new information is provided to you, your consent to continue to participate in this study will be re-obtained.

What about privacy and confidentiality?

The only people who will know that you are a research subject are members of the research team. No information about you, or provided by you during the research, will be disclosed to others without your written permission, except:

- if necessary to protect your rights or welfare (for example, if you are injured and need emergency care or when the University of Missouri-St Louis Institutional Review Board monitors the research or consent process); or
- if required by law.

When the results of the research are published or discussed in conferences, no information will be included that would reveal your identity. Audio-tape recordings of you will be used for educational purposes only and your identity will be protected or disguised. Any information that is obtained in connection with this study, and that can be identified with you, will remain confidential and will be disclosed only with your permission or as required by law.

Only the researcher and the transcriber will have access to your recording. The recording will be erased at the conclusion of the study.

The only identifying information requested in the questionnaire is your name and email address. These are both optional and are solely for contacting you should any follow-up questions or clarification become necessary. They will not be used in the paper or in any presentation of the paper. Any proper names you should chose to use in your interview, either consciously or inadvertently (e.g., name of your high school, name of a science teacher, or name of a highly specific science program) will not be used in the paper or any presentation of the paper.

No other uses of this data are contemplated. Should a second study be undertaken that would benefit from your responses, your permission will be solicited first. The questionnaires will be destroyed one year after completion of the study (when the dissertation has been completed and approved). Until then, all printouts and disks will be stored in a locked filing cabinet at my school and all computer files will be password protected.

The researcher will use your information until the dissertation has been completed and approved by the dissertation committee. At that point, the researcher will remove the identifiers from your information, making it impossible to link you to the study.

Do you already have contact restrictions in place with UM-SL? [ ] Yes [ ] No

(Example: no calls at home, no messages left for you, etc.)

Please specify any contact restrictions you want to request for this study only.

____

____

What are the costs for participating in this research?

There are no research costs for participating.

Will I be paid for my participation in this research?

There is no remuneration of any kind for participation in this study.

Can I withdraw or be removed from the study?

You can choose whether to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You also may refuse to answer any questions you do not want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. If you decide to end your participation in the study, please complete the withdrawal letter found at http://www.umsl.edu/services/ora/IRB.html, or you may request that the Investigator send you a copy of the letter.

Who should I contact if I have questions?

The researcher conducting this study is Andrew D. Shaw. You may ask any questions you have now. If you have questions later, you may contact the researcher at 636-530-9560 or ashaw@wcastl.org.

What are my rights as a research subject?

If you have any questions about your rights as a research subject, you may call the Chairperson of the Institutional Review Board at (314) 516-5897.

What if I am a UMSL student?

You may choose not to participate, or to stop your participation in this research, at any time. This decision will not affect your class standing or grades at UM-SL. The investigator also may end your participation in the research. If this happens, your class standing will not be affected. You will not be offered or receive any special consideration if you participate in this research.

What if I am a UMSL employee?

Your participation in this research is, in no way, part of your university duties, and your refusal to participate will not in any way affect your employment with the university or the benefits, privileges, or opportunities associated with your employment at UM-SL. You will not be offered or receive any special consideration if you participate in this research.

Remember: Your participation in this research is voluntary. Your decision whether to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship.

You will be given a copy of this form for your information and to keep for your records.

I have read the above statement and have been able to express my concerns, to which the investigator has responded satisfactorily. I believe I understand the purpose of the study, as well as the potential benefits and risks that are involved.

All signature dates must match.

____

Participant’s Signature Date Participant’s Printed Name

____

Researcher’s Signature Date