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ABSTRACT

Science, particularly the physical sciences, has undergone several paradigm shifts during history. The modernistic and mechanistic world that was viewed through the lens of Newton's laws no longer offers valid answers to present-day questions. This paper examines four themes: the evolution of physics, the evolution of chemistry, the evolution of science education, and the impact of postmodernism on science education. The need for emancipation from the modernistic paradigm is highlighted in order to foster critical thinking and greater scientific literacy. It is argued that future educators need to be emancipated in order to emancipate their students. Contains 61 references. (JRH)

Paradigms and Postmodernism in Science and Science Education

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Abstract

Science, particularly the physical sciences, has undergone several paradigm shifts during history. How we teach and learn science reflects this evolution. From the times of the Mertonians to the beginnings of the quantum revolution, science has become more and more mathematical, more critical, more fact and precision-oriented, and less tolerant of alternative views.

The modernistic and mechanistic world that we have viewed through the lens of Newton's laws no longer offer valid answers to our present-day questions. With the introduction of quantum theory and relativity, we have realized that new approaches, with a contingency of conditions, offer us the freedom to find creative answers to creative questions.

We need to emancipate ourselves from the modernistic paradigm if we are to foster critical thinking and greater scientific literacy. Future educators need to be emancipated in order to emancipate their students. If this doesn't take place, we will continue to be weighed down by the same inertia that Newton proposed as a tendency to maintain stasis.

Introduction

Paradigmatic shifts play an important role in how one views physical concepts and accepts laws of nature. From Aristotle to Newton, from Franklin to Rutherford, and from Brahe to Einstein, there are many episodes throughout history that indicate the painstakingly long time it takes for old ways of thinking to give way to newer, more plausible theories. Not only is this evident in the physical sciences (e.g., chemistry and physics), but in the way people are schooled in the physical sciences.

In this paper, I wish to examine four themes: (1) the evolution of physics, (2) the evolution of chemistry, (3) the evolution of science education, and (4) the impact of postmodernism on science education. How the physical sciences evolved during the past 600 years in some ways transferred to how we have taught those sciences during the past 100 years. How society's postmodern condition evolved during the past 200 years has in turn transferred to how scientists and nonscientists are "schooled" in the physical sciences. Consequently, two dominant paradigms clash: the paradigm of educating learners to lead themselves (postmodernism) and the paradigm of instructing learners to be perpetually led (modernism). At risk are four vital components of science learning: the curriculum, pedagogy, cognitive development, and personal identity (Pushkin, 1997a).

> How did we become the educators we are today? Did someone take us by the hand, show us a recipe, and coach us to perfect it? Or did we pose the most difficult questions of retrospection? Educators cannot afford narrow viewpoints; neither can learners. Knowledge is not always clear-cut and absolute, and sometimes it needs to be evaluated for its strengths and limitations. Knowledge is relative, contextual, and evolves according to its own timetable; learning shares these attributes. Educators and learners alike, need to be sensitive to this, share their perspectives and insights, and chronicle each others' journey through knowledge. (Pushkin, 1997a, p. 3)

The physical sciences and science education have become academic domains suffocated by their proud traditions; unfortunately the time has come to change radically. Does this mean dispose of tradition and "clean house" completely? No; *radical change* means to change quickly in normative time. Change in one's epistemology, pedagogy, curricula, or cognitive framework cannot require an entire academic career to occur, nor can such change require at least the graduation of a generation of students. This type of change must be on a daily, hourly, and even momentary scale; science educators and learners alike need to be more enlightened in comparison to their prior introspection. This type of change requires courage and critical examination of tradition on everyone's part.

Allow me to share an analogy. Being Jewish, I was brought up in a very traditional home with the standard traditional values (e.g., keeping kosher, and observing the Sabbath). Unfortunately, many of those traditions have the potential for unhealthy living (e.g., eating red meat, diets high in starch, sodium, and cholesterol, and being sedentary). As I became older, I chose to become a vegetarian, and regularly exercise. Do I keep kosher? Yes. Do I observe the Sabbath? To the best of my ability and common sense. Is it heresy to make soup with tofu as opposed to chicken? Or an eggplant casserole versus brisket? Or a tomato omelet with brown rice instead of lox and bagels? I don't think so; I can still present a traditional spirit with my creative modifications.

So why can't we do this with introductory chemistry and physics courses? Or science teaching methods courses? Or science education research dissertation projects? Why must all textbooks begin the same way in chapter one? Why must textbooks and lab manuals be used? Why must lesson plans be written in boxes on preprinted sheets? Why must "Science 101" precede "Science 102"? Why must assessment be dominated by multiple-guess items and "plug-and-chug" exercises? Must dissertations have null hypotheses? Radical change need not involve 180-degree turns; radical change only needs broader perspectives, welcomed alternatives, and shorter time intervals.

(1) The Evolution of Physics

> The earliest attempts at a physical science took place when astronomy developed beyond the stage of pure myth-making because agricultural society required information about the starts of the seasons. This knowledge was accumulated by the priesthood, which thereby acquired even more power. This greater power led to astronomy-oriented religions, not only in Egypt and Babylon, but even in England. Inevitably there were then power struggles between religious astronomy and the secular authorities. (Schroeer, 1972, p. 57)

Physics has its origins from Ancient Mediterranean and Greek cultures; however, its present-day origins from the Mertonians of the 14th century (Wallace, 1971). The Mertonians are credited with making contributions to the mathematics Newtonian mechanics was built from (Wallace, 1971). According to Schroeer (1972), Greek Science "failed" due to four possible factors:

(1) the feeling of fate
(2) science was part of philosophy
(3) experimentation was quite rare
(4) technology was nonexistent.

The Mertonians failed to sense the need for experimentation; they did, however, sense the need for scientific theory to be empirical, with cause-and-effect relationships (Wallace, 1971). It wasn't until Galileo that the experimental nature of physics manifested itself in mechanics, specifically the study of motion; unfortunately, his work conflicted with Church doctrine (Schroeer, 1972).

> The impact of Newtonian mechanics went far beyond just changing scientific attitudes. Within five years of its appearance, Newton's work was publicly referred to from an English pulpit as "incontestably sound." And it was the godparent to the whole Age of Enlightenment. The new thinking was reflected in a change in vocabulary. In the 13th century the important words, words whose meanings were taken for granted, included God, sin, grace, salvation, and heaven; in the 18th century these were replaced by nature, natural law, reason, humanity, and perfectibility. The new vocabulary allowed change from the pessimistic Christian doctrine of man's depraved nature, burdened from birth with original sin, to the optimistic view that all men are born

with their minds a clean slate on which either good or evil can be written by society. (Schroeer, 1972, pp. 94-95)

In his work, Newton brought about a merger between the empirical nature of science demanded by the Mertonians and the experimental nature developed by Galileo. However, Newton's laws focused only on what could be seen (e.g., motion and planets). Although Newton used the term momentum, the originators of the conservation laws were Hooke, Wallis, Wren, and Huygens; Newton's laws were able to explain many -- albeit not all -- natural phenomena (Spielberg and Anderson, 1985). There were phenomena that we sensed, yet could not necessarily see.

The 18th and 19th centuries were primarily focused on the concepts of energy, heat, temperature, work, states of matter, electricity, magnetism, and light. Inventions by Franklin, Watt, Volta, Faraday, and Roentgen only intensified the level of study. By 1900, the vocabulary of physics included such terms as *specific heat*, *latent heat*, *enthalpy*, *entropy*, *field waves*, *dielectrics*, *adiabatic*, *isothermal*, and *photoelectric*.

However, there remained natural phenomena to study: the structure of an atom, radioactive decay, kinetic theory, transmission of light, relative motion, the existence of a vacuum, space and time, as well as origins of the universe. With each new finding, questions arose; with each question, theorization and experimentation began.

Consider the experimental findings of J.J. Thomson and Robert Millikan, when they verified that the electron was a negatively-charged subatomic particle. Until that time, there was still acceptance that the atom was the smallest form of matter. How could we rationalize that something unseen by the human eye, considered indestructible, was composed of smaller constituents?

Consider the experimental findings of Ernest Rutherford and James Chadwick, when they identified a nucleus, protons, and neutrons. How could Thomson's "plum pudding" model be discarded so soon by a loyal former student? How could a constituent of the atom have constituents of its own? How could subatomic particles have mass and no charge? How could Coulombic forces exist?

Consider the quantum theory Max Planck proposed to explain blackbody radiation; how could energy be *quantized*? Wouldn't this completely contradict the kinetic theory? How could this theory be based on a string in a box? How could there be a minimum oscillation frequency? What would happen to this theory five years later when Albert Einstein proposed his equation for the photoelectric effect, not to mention his postulates for general and special relativity?

And so it went for the first half of the 20th century -- Niels Bohr's correspondence principle, Henry Moseley's plot, Louis De Broglie's wave-particle duality principle, Ludwig Boltzmann's statistical mechanics, Erwin Schrodinger's equation, Werner Heisenberg's uncertainty principle, and Wolfgang Pauli's exclusion principle. A new mathematical theory; a new series of experiments. New findings; new theories. New models; new questions. New questions; new ideas.

The second half of the 20th century has seen the likes of Murray Gell-Mann, Hideki Yukawa, Richard Feynman, Leon Lederman, and Ken Wilson. Our vocabulary has expanded to include such terms as quarks, mesons, muons, haldrons, neutrinos, bosons, quantum entropy, quantum electro-dynamics, big bang theories, superconductivity, and artificial intelligence. However, there remain fundamental tenets from physics' origin, namely empirical analysis and systematic experimentation.

Physics the science requires a qualitative understanding of phenomena in order to formulate quantitative theories and identify quantitative parameters. Unfortunately, the use of mathematics and the tradition of process have masked physics the science; to the introductory student, *physics is math, not science*. New learners of physics are indoctrinated into an apprenticeship, one the demands obedience and mastery of mainstream standards (Pushkin, 1997b). The potential for creativity still exists, but our teaching stunts that potential; the beauty of science is bogged down by SI unit conversion exercises, redundant calculation exercises, and syllabi constructed to race through content or weed out students.

(2) The Evolution of Chemistry

Alchemy's origins go back to the Greeks; this mode of thinking dominated Western culture and science until the 16th century (Silberberg, 1996). The primary focus of alchemy was precious metals and beauty. Metals with little luster were considered *baser*; those with more were considered *purer*. Although the alchemists provided the foundation for many laboratory techniques, their scope of chemistry was considerably limited. The scope of chemistry broadened after the medieval period; the practice of medicine with products of plants and herbs established the foundation for pharmacy and more sophisticated laboratory techniques.

However, it was not until the latter half of the 18th century that Antoine Lavoisier presented clearer explanations of chemical reactions and introduced the notion of conservation of matter. Around the same time, Joseph Priestly discovered oxygen, helping us develop an understanding of the air we breathed.

The early 19th century was dominated by John Dalton's atomic theory and Amedeo Avogadro's concept of the mole. It was Dalton who formulated the laws of definite and multiple proportions, such that chemical formulas broadened our understanding of how substances reacted with each other. Avogadro's concept of the mole established the foundation for the empirical nature of chemistry (i.e., stoichiometry).

Other contributions that evolved from this period of time were Henry LeChatelier's concept of chemical equilibrium, the discoveries of several elements by Sir Humphrey Davy, Gay-Lussac's gas law, the concept of enthalpy and the technique of calorimetry, the voltaic cell, and Michael Faraday's electrochemistry experiments.

However, during the latter half of the 19th century, the knowledge base of chemistry grew beyond the macroscopic view. Friedrich Kekulé and Archibald Couper proposed the simple structure theory of organic molecules (Tarbell and Tarbell, 1986). Dimitri Mendeleev devised the first periodic table of elements. Rudolf Clausius, Josiah Gibbs, and J.H. van't Hoff established the foundation for chemical thermodynamics and chemical kinetics (Atkins, 1982). Svante Arrhenius identified the chemical nature of acids and bases. Chemistry was taking on a more microscopic perspective, as researchers sought underlying reasons for reactions between substances.

However, as the 19th century ended and the 20th century began, chemistry benefited from the contributions of physics. From J.J. Thomson, Robert Millikan, Ernest Rutherford, James Chadwick, Henry Moseley, Niels Bohr, Erwin Schrodinger, Wolfgang Pauli, and Gilbert Lewis -- we learned of the existence and nature of the proton, neutron, and electron, energetic states of an atom, paired and unpaired valence electrons, the nature of orbitals, and the characteristics of elements. From very microscopic measurements and mathematical theories, we gained incredible insights on chemical behavior to rationalize our macroscopic observations.

It was during this period of time that chemistry became increasingly quantitative and abstract. Chemistry itself was becoming more theoretical; research seemed to be more fundamental than applied. Chemistry and physics increasingly mirrored each other, a phenomenon that still exists today in many respects.

However, with the onset of the first and second world wars, chemistry -- as well as physics -- developed a more application-oriented nature. Fritz Haber built upon LeChatelier's principle to increase the yield of commerical ammonia in Germany; Mildred Cohn and H.C. Urey countered this with acid catalysis oxygen-exchange reactions for the American Cyanamid Company (Tarbell and Tarbell, 1986). Materials science research expanded; alloys and polymers became more valuable commodities. Technology became more sophisticated, as both industry and academia worked together to develop newer and more-effective modes of transportation and communication.

As space exploration and the cold war became a boon for physics in the 1960s and 1970s, medicine, the pharmaceutical industry, and oil companies well-served chemistry. New drugs to combat disease eliminated fears of prior generations. Alternative fuel sources became another area of research for both physics (e.g., nuclear) and chemistry (e.g., "gasohol"). Advances in spectroscopy, chromatography, and crystallography enabled chemists to learn more about molecular structure, which in turn enabled them to understand more about the nature of reactions.

Who would have thought that chemistry would make such an impact on the food industry, where alternative sweeteners (e.g., aspartame) and fat substitutes (e.g., olestra) are prevalent in many packaged products? Who would have thought that chemistry would make the advances it has towards fighting cancer and AIDS? Who would have thought that chemistry would lead us to understand the difference between "good cholesterol" and "bad cholesterol"? The contributions of chemistry in our everyday lives is immeasurable.

However, for all the potential and creativity chemistry presents, the field of chemistry has become very much like physics -- a empirically-dominated field that requires obedience. Introductory chemistry courses in our high schools, colleges, and universities reflect this all-too-painfully. General chemistry for science majors is "watered-down P-Chem;" a high school course is "watered-down General Chem." It is worse in introductory courses for nonscience majors. Those who teach such course often "dilute" their lecture notes from General Chemistry; unfortunately the only "diluted" aspect of the course is the instructor's expectation of the students (Babcock, 1996; Hoogstraten, 1996; Pushkin, 1996a). In the academic setting, teachers of chemistry and physics alike struggle with their purpose -- *am I teaching a subject, or am I educating students on my field?*

What are the expectations of the chemical industry? Companies desire graduates who can think critically and solve problems; however, when these graduates (even Ph.D.s) arrive, they are expected to learn routines and serve under someone else. Chemists are not paid to think or develop new ideas; they are paid to perform assigned duties. The young chemist is an apprentice, be it at the bench in industry, a post-doctoral position in academia, or as a junior faculty member in a teaching environment.

Can we ever expect to see the same accomplishments in chemistry that prior generations of chemists made? Time will tell; the present does not indicate so, as the expectations of academia and industry appear to dictate. However, as new problems develop in society and nature, future chemists may encounter more opportunities to conduct long-term studies, discover new chemicals, and learn new applications.

(3) The Evolution of Science Education

> Commissioner of Education for Massachusetts, David Sneeden, led the fight for the efficiency perspective as he advocated the establishment of separate vocational schools to train students in specific job skills. To create an efficient society, Sneeden argued that schools must produce workers who valued tradition and upheld virtues such as obedience, punctuality, and deference to authority. Opposing Sneeden was John Dewey who contended that the vocational education Sneeden proposed viewed student needs as subservient to economic needs defined as the interests of employers. Sneeden's efficiency, Dewey argued, meant adapting students to the existing industrial order. Dewey felt that workers should be masters of their own industrial fate and worker education should develop intelligence in such a way that workers could envision more democratic work arrangements. On a variety of levels Dewey recognized over eighty years ago what we have called the fragmentation of modernism. He also recognized the ways that schools contribute to this fragmentation. (Kincheloe, 1995, pp. 10-11)

Science Education's origin in the United States appears to be the 19th century, as scientific discoveries and the industrialization of society became more prevalent. Prior to this, science itself was essentially nonexistent in the curriculum; the infusion of science intensified the debate between modern studies and classic studies (DeBoer, 1991). The study of science, according to its proponents, was beneficial in the development of *mental discipline*.

The leading proponent of science in the curriculum was Edward Livingston Youmans (circa 1870), who felt science teaching should begin for children at the earliest age of schooling, since they had "a vast capability of accumulating simple facts" (DeBoer, 1991, p. 7). Science teaching would emphasize the use of one's senses, developing observation skills, and determining simple relationships. As children grew older, Youmans asserted, their observation skills would be more systematic, enabling them to be more inductive and deductive in their reasoning powers. Science education would begin with the more-certain physical sciences, then progressively include the more-subtle biological sciences.

Youmans was not the only proponent of science in the curriculum. Thomas Huxley considered science good preparation for careers in medicine, engineering, and the clergy. Herbert Spencer considered science a viable avenue to discuss evolution and educate children on self-preservation in a modern industrial society (DeBoer, 1991). However, a common theme appeared in each of their arguments; science was tangible to life and dynamic, unlike the classics which were considered *dead and dogmatic*.

Charles W. Eliot, president of Harvard University from 1869 to 1895, was also a strong proponent of science education -- at the elementary, secondary, and college levels. Unfortunately, his enthusiasm waned, as the quality and amount of science taught at the secondary and college levels needed improvement. However, what Eliot found most concerning was the "artificial difficulty of the curriculum and its oppressive drudgery" (DeBoer, 1991, p. 32); the focus dramatically shifted from what was learned to how accurately it was learned. Eliot's concerns were shared by others, but his concerns were somewhat dismissed as *part of science*; Michael Faraday was one who shared this opposing view.

> A long-existing problem in our schools, particularly in science classes, is the need for correctness. Piagetian conceptual change focuses on coming to consensus with the "accepted conception;" alternatives are misconceptions (Maloney, 1994). In modernist classrooms, we teach students that there is only one scientific method, only one way to write a lab report, only one way to formulate a hypothesis, and only one way to define scientific terms. If we think of the three stages of conceptual change: assimilation, accommodation, and equilibration, the message becomes loud and clear: here is the correct way to look at it, accept it, and understand that your way is wrong. If your interpretation is contrary to the book's, you are questioned, if not interrogated. If your interpretation comes from a journal or author that is "not mainstream," you are scolded, if not sanctioned. If you are taking time to contemplate things that others deem insignificant, then you are misguided. (Pushkin, 1995, p. 13)

In the 1890s, the Committee of Ten, a committee of college and school leaders (headed by Charles Eliot), presented five primary objectives for science study:

(1) Developing powers of direct observation
(2) Developing the ability to form clear mental images of concepts
(3) Developing reasoning powers
(4) Gaining new knowledge via observation and experimentation
(5) Developing calculation skills in order to solve problems

The science curriculum was to include chemistry, physics, biology, and geography. Students were to have laboratory experiences, where they could investigate their own ideas and test current knowledge. The emphasis in science education was becoming hands-on; the textbook was considered a deterrent to learning (DeBoer, 1991). Science education for the first quarter of the 20th century had the following characteristics: exploratory, practical, relevant, and integrative.

According to Rosen (1954), as early as 1834, some college professors urged the use of demonstration apparatus to improve the teaching of natural philosophy (an older term for the natural sciences, which included chemistry, geology, physics, and zoology) in secondary schools. However, it was not until the 1870s when the laboratory method (i.e., hands-on experiences) of teaching the physical sciences appeared more regularly in high schools. Rosen also noted the difficulty in determining how many secondary schools had physics courses in which students actually performed experiments individually, since the term "laboratory method" could also have included teacher demonstrations. Two potential factors causing resistance to the introduction of physics laboratory courses in high schools were considered: (1) prohibitive cost for many schools, and (2) scarcity of teachers trained in laboratory methods. While in 1880, few schools offered courses in elementary physics with laboratory work, by 1906 this proportion was much greater (Rosen, 1954).

For example, Rosen (1954) attributed the rise of lab activities (to be contrasted with *experiments* later in this section) in high school physics to four influences:

> (1) The growing feeling that a curriculum emphasizing science was more important for the demands of the industrial age than the older classical curriculum.
> (2) The increasing emphasis on laboratory work and empirical research in universities and colleges.
> (3) The influence of college admission requirements on the high school curriculum.
> (4) The peculiar optimistic American habit of popularizing to emotional extremes certain "progressive" ideas (p.204).

The term "progressive" implies moving toward the future. With the furthering of industrialization, education needed to prepare students for a different world of adult life -- one of new machines, opportunities, conveniences, and applications. The period between 1917 and 1957 is commonly referred to as the "Progressive Era in American Education", since Americans were so receptive to many new and innovative ideas. During this era, issues of importance were child-centered education, the social relevance of knowledge and real-world applications. Another major issue elaborated in this era was the need for school learning to be both meaningful and enjoyable (DeBoer, 1991).

If one were to look at a list of articles published in *Science Education* during its early years (1916-1930), a number of articles debated the value and effectiveness of hands-on experiences in science courses (e.g., Brownell, 1918; Goldsmith, 1918; Horton, 1929; Stone, 1918; Woodhull, 1918). In fact, near the end of the first world war, some common themes pertaining to school science labs were relevance, project work, appreciation for science, and stimulating the spirit of inquiry (Stone, 1918; Woodhull, 1918). It should not be surprising that the importance of relevance was a recurrent theme in the literature. Lab activities were heavily criticized at the start of the 20th century for not being relevant enough (Rosen, 1954).

Although articles offered their share of step-by-step lab activities with little accompanying research (e.g., Stone, 1918; Woodhull, 1918), the emphasis remained for lab activities to be applicable and practical, as well as introduce students to new knowledge through inductive inquiry-oriented lab activities (Brownell, 1918). The key feature of these activities was to enable students to acquire information first-hand, rather than through authoritative statements in textbooks. If hypotheses and laws were to be formulated, these were to come from students, as opposed to being given to students.

An issue arises with the term "lab activities." Because of the positivist view of science and experimentation, this term is commonly reserved for students in a learning environment; *experiments* are considered the work of experts only. While this may be true to a degree in the context of scientific research, this is a very derogatory distinction in the context of learners. When one experiments, one is testing ideas and making observations and assertions; ultimately, the desired outcome is to learn something new. Whether expert scientists agree or not, students are constantly experimenting;

they are learning something new, even if we do not consider it new (Pushkin, 1987, 1996b). Perhaps the term *investigation* might serve as a pedagogical compromise between the clashing paradigms.

Project work was introduced by William Heard Kilpatrick in 1918 (DeBoer, 1991). The goal of project work was to make socially relevant problems the basis for organizing the curriculum, in contrast with concepts of specific science disciplines (DeBoer, 1991). Project work was designed for students to work individually, an approach well-supported by many, including John Dewey and Franklin Bobbitt. The attractive feature of project work was providing students an opportunity to solve problems that had personal significance. Problems were to be relevant to an individual student's daily life; solutions were to be practical. Dewey was a proponent of making the curriculum relevant to the experiences students already had (McNeil, 1990).

Although project work was popular, the costliness of materials and equipment significantly threatened its implementation. Thus educators sought more cost-effective alternatives to individual student lab investigations, such as group lab activities and teacher demonstrations (DeBoer, 1991). Project work became less prevalent in the science curriculum towards the end of the 1920s.

Both Brownell (1918) and Goldsmith (1918) were proponents of field trips. Through field trips, students could acquire information first-hand instead of reading authoritative statements in textbooks. Nature study, considered to be a very important part of elementary science education in the early 20th century, was to include field trips, where the primary goal was to develop a true appreciation of one's natural surroundings and living things. Science education in the early grades was meant to introduce children to new knowledge via inductive inquiry, or the discovery method. In the upper grades, the accent became more utilitarian and civic, broadening experiences in the world and deepening appreciation for the world.

However, as the 1920s progressed, more interest developed regarding the effectiveness of individual student work versus teacher demonstrations. Questions were raised regarding efficient use of time, space, and materials (Anibul, 1926; Klopp, 1929; Watkins, 1929). Questions were also raised regarding the long-term learning outcomes for lab activities (Reidel, 1926; Moore et al., 1929; Klopp, 1929; Horton, 1928, 1929). Some science educators science educators supported the standardization of lab activity topics and protocols as a uniform curriculum for all schools (Brown, 1922), while others questioned the reliability and validity of standardized tests as ways to assess learning outcomes from the lab (Horton, 1928, 1929). There were also criticisms that the lab was failing to be practical or relevant; lab activities were criticized for containing "cook-book" protocols (Watkins, 1929).

The overcrowding of classrooms following the first world war, intensifying problems with lab space and money, was a genuine concern (Wooten, 1931). Overcrowding is attributed to several factors, most notably the increased age of students in school and the lagging growth in the numbers of classroom teachers. Additionally, since the lab had become a mandatory component of the science curriculum (Wooten, 1931), many students lacked the motivation to participate in lab activities. As a result, lab activities often became just another assignment for many students, where the ritualistic following of directions to complete the task would have been of top priority. This only served further to make issue of the overcrowding in science classrooms. The purpose of lab activities was seemingly unclear (Watkins, 1929); this appeared to mirror the evolving purpose of science education.
However, a new question was raised in the literature during the 1930s (e.g., Edmiston, 1933; Taylor, 1937; Burnett, 1939): which was more important, content knowledge or procedural knowledge?

Because the population of students was changing in the science classroom, it was suggested that labs for all students might not have the same impact as if reserved for motivated students only (Wooten, 1931). It was also suggested that classroom demonstrations would have more impact on students, since students would be participating together within a structured format (Stathers, 1933). However, the underlying reason for these suggestions appear to be the desire to save teachers time and effort. The issue of efficiency does not appear to reflect student learning as much as it does teacher convenience.

Edmiston (1933) proposed four purposes for lab activities:

(1) Develop an exactness in measurement.

(2) Develop an ability to apply knowledge.

(3) Develop an ability to devise lab procedures.

(4) Develop an ability to complete devised procedures.

These purposes were considered to emphasize perceptual or direct experiences for the student, something Edmiston (1933) believed was not stressed enough in education. Considering the skills that students would need in life beyond their formal education, Edmiston (1933) felt school labs were not necessarily meeting those needs. Although Goldstein (1937) believed that lab experience was developing better resourcefulness in students, he too questioned the long-term carry-over benefits that students would experience beyond their formal education.

Testing student learning from the lab was a concern (Stuit and Englehart, 1931). Edmiston (1933) reported that while written testing was the only means of assessment used, test results might not tell an educator anything about student learning. A minimal relationship was measured between content knowledge and procedural abilities. Stuit and Englehart (1931) recommended the administration of additional tests in order to measure the following desired outcomes: (1) laboratory technique, (2) manipulative skills, (3) interest in science, and (4) scientific attitude. Although results were favorable for students having hands-on experience versus observing teacher demonstrations (Nash and Phillips, 1927; Horton, 1928), little significance was observed regarding achievement differences (Stuit and Englehart, 1931). The issues of European education had become American education issues as well.

> The strong historical connection between academic subjects and external examinations is only partly explained by 'the need to teach these subjects in such a way and to such a standard as will ensure success in the School Certificate examination.' The years after 1917 saw a range of significant development in the professionalisation of teachers. Increasingly, with the establishment of specialised subject training courses, secondary school teachers came to see themselves as part of a 'subject community.' The associated growth of subject associations both derived from and confirmed this trend. This increasing identification of secondary teachers with subject communities tended to separate them from each other, and as schools became larger, departmental forms of organisation arose which reinforced the separation. (Goodson, 1993, p. 30)

Burnett (1939) was a proponent of reflective thinking in science courses. He considered the lab an excellent place for reflective thinking, where problem solving skills could develop. The lab, as opposed to textbook knowledge or student attitudes and habits, was where ideas and initiative began. The process of science was considered the best vehicle for learning science. On the other hand, Taylor (1937) considered content knowledge the best vehicle for learning science. Taylor's practice was for first-year science courses to have no lab component, followed by a second-year course with a lab. The rationale was that it would be more advantageous for both the students and the course if students had their knowledge foundation before performing experiments. It was also pointed out (Taylor, 1937) that more advanced students would be in the lab course, again suggesting that the lab component might have been structured more for teacher convenience than student learning.

The debate between content knowledge and procedural knowledge was further fueled by the National Society for the Study of Education's (NSSE) Thirty-First Yearbook Committee. The Yearbook Committee not only had strong feelings towards the teaching of socially relevant science content, but also believed that students should learn about scientific methodology and practice (DeBoer, 1991). Surprisingly, the Yearbook Committee also supported teacher demonstrations versus students performing lab activities, since it was somewhat doubtful as to whether the scientific method should be primarily learned in the school lab (DeBoer, 1991). It should be noted that the Yearbook Committee was heavily influenced by the economic conditions resulting from the Great Depression (DeBoer, 1991). This was also the period of time when Harold Rugg and George Counts led the social reconstructionist movement; the curriculum was considered to have a relationship with the social, political, and economic development of society (McNeil, 1990).

Nonetheless, the Yearbook Committee identified seven purposes to laboratory work:

> (1) The development of simple laboratory techniques, such as weighing, glass bending, microscopic manipulation, etc.
>
> (2) Providing and establishing for the pupil himself principles which have long since been well established and generally accepted.

(3) Using the laboratory as an instrument for object, or "thing," teaching, according to the historical concepts of Pestalozzi, Comenius, and Basedow.

(4) Using the laboratory for the purpose of developing better understanding and interpretations of the principles of science, as a means of better illustration.

(5) To produce training in scientific method.

(6) As a means of possible training in the experimental solution of the pupil's own problems.

(7) The use of the laboratory as a workshop for the study of science problems which arise in the science class or in the life of the pupil. (DeBoer, 1991, p. 113)

Francis Curtis, a professor at the University of Michigan during this time, identified three major goals of the laboratory for the Yearbook Committee (DeBoer, 1991):

(1) "Teaching the pupil to manipulate" or permitting the pupil to "learn to do".

(2) Students should learn to interpret experimental data.

(3) "Teaching the pupil the concept of the scientific method" (p. 114).

Curtis, according to DeBoer (1991), considered the laboratory to have limited usefulness, where its primary benefit was teaching students certain lab procedures. Learning the scientific method and analyzing data would not necessarily require individual laboratory work; a teacher demonstration was considered to be a potentially better avenue. Curtis' aforementioned goals of the lab were further developed in a paper (Curtis, 1940) that looked more broadly at general science education. Curtis, an opponent of memorizing facts, offered four major goals for science learning:

(1) To effect a functional understanding of important principles of science.

(2) To insure a facility in the use of the elements of the scientific method in solving problems.

(3) To afford a training designed to develop scientific attitudes, with special emphasis upon their social implications and applications.

(4) To insure a realization of the appropriateness and the potential values of activities related to science in leisure pursuits and hobbies (Curtis, 1940, p.121).

With the United States' entrance into World War II, science education took on a new tone. Industry and agriculture were expected to maintain productivity levels despite a labor force depleted by the military. The armed forces needed recruits and officers who were literate, quantitative, and technically-inclined. Qualified personnel were in demand. Science teachers were in demand. The government and education community alike were confronted with issues that required immediate and pragmatic solutions (DeBoer, 1991).

However, the issues became more obvious *after* World War II. The number of college science majors increased dramatically with the return of GIs; unfortunately, the number of science teaching faculty was significantly deficient. The Cold War with the Soviet Union was born with the Atomic Age. Science needed to recruit the best students; society needed to be more literate in science.

> One of the reasons that the period following the war was particularly interesting was because it provided insights into what other segments of the society besides professional educators thought of science education. Scientists had been largely uninvolved in discussions about science education since the turn of the century. Then it was commonplace for people such as Charles Eliot, Ira Remsen, and John Coulter to be involved in the debate on education. Fifty years later, scientists began asserting themselves again, and, along with representatives of the military, they created a new dialogue on education. What was most striking about this dialogue was that for the most part its content was much the same as that of professional educators of the previous 40 or 50 years. The only new ideas that were advanced were that to protect our national security special provision should be made for gifted and talented students and that science had a legitimate general education role in higher education. The ideas of progressive education, especially the emphasis on applied and functional studies, were still strong in the late 1940s and early 1950s, and this was reflected even in the writings of the scientists themselves. (DeBoer, 1991, pp. 137-138)

So what happened? A cold "wake-up call" to the United States.

> A half-century of noble efforts to make science meaningful and relevant to all students had produced a science program that was satisfying neither traditionalists nor progressives. Energized by the excesses of the life adjustment educators, traditionalists would grab hold of the science curriculum and dramatically alter the direction of science education in the decade ahead. (DeBoer, 1991, p. 146)

> When the Soviet Union launched its earth-orbiting satellite *Sputnik* in 1957, the U.S. government backed these initiatives of the scientists with enthusiasm and financial support. What followed were two decades of federal involvement in science teaching and the development of an approach to science education that was focused on the logical structure of the disciplines and on the processes of science. (DeBoer, 1991, p. 147)

PSSC Physics. BSCS Biology. CHEM Study. ESCP Earth Space Science. The influence of Joseph Schwab, Jerome Bruner and the 1959 Woods Hole Conference was asserted on mathematics and science education; reform, albeit lacking definition, was primarily driven by the demands of national security and the "space race" (DeBoer, 1991).

> The main objective of this work has been to present subject matter effectively -- that is, with due regard not only for coverage but also for structure. The daring and imagination that have gone into this work and the remarkable early successes it has achieved have stimulated psychologists who are concerned with the nature of learning and the transmission of knowledge. (Bruner, 1960, p. 2)

> Something had to be done to assure that the ordinary decision maker within society would have a sound basis for decision. The task was to get started on the teaching of science and, later, other subjects. They were innocent days. But beware such judgments rendered in retrospect. At worst, the early period suffered an excess of rationalism.
>
> The prevailing notion was that if you understood the structure of knowledge, that understanding would then permit you to go ahead on your own; you did not need to encounter everything in nature in order to know nature, but by understanding some deep principles you could extrapolate to the particulars in mind.

Producing curriculum turned out to be not quite as we academics had thought. Something a bit strained would happen when one caused to work together a most gifted and experienced teacher and an equally gifted and experienced scientist, historian, or scholar. There was much to be learned on both sides and the process was slow and decisions had to be made about the level at which one wanted to pitch the effort -- the college-bound, the "average," the slum kid?

The movement of which *The Process of Education* was a part was based on a formula of faith: that learning was what students wanted to do, that they wanted to achieve an expertise in some particular subject matter. Their motivation was taken for granted.

When any group is robbed of its legitimate aspiration, it will aspire desperately and by means that outrage the broader society, though they are efforts to sustain or regain dignity. Inequity cannot be altered by education alone, another lesson we have learned in the past decade.

Reform of curriculum is not enough. Reform of the school is probably not enough. The issue is one of man's capacity for creating a culture, society, and technology that not only feed him but keep him caring and belonging. (Bruner, 1971, pp. 18-21)

As we examine the evolution of Bruner's thoughts, it becomes evident that the science education reforms of the 1960s failed for many reasons, among them being: (1) insufficient consideration of all learners in a democratic society (Kincheloe, 1993; McNeil, 1990); (2) a disregard for teachers in a democratic society (Kincheloe, 1993; Novak, 1994; Romey, 1973); (3) insufficient sensitivity towards the goals of a diverse society (Bradley, 1976); (4) insufficient thought regarding the meaning of "learning science" (Lunetta and Tamir, 1980).

Unfortunately, the same motivations for science education reform in the 1950s and 1960s remain in the 1980s and 1990s. By the same token, the same issues confronted by reformists of 30 years ago remain as well.

One most important lesson is that a true process of reform is all-engaging. In places where programs work, ideas are solicited from faculty and implemented locally by the department. Where programs don't work, some "creative loner" is proceeding without internal support and commitment. lasting change occurs, as far as I can identify it, when everyone wants it -- when there is a near universal "buy-in" so that the commitment is collective. (Tobias, 1992, p. 17)

When *A Nation at Risk* was first published in 1983, the debate on science education in the United States had come full-circle. Federal and State legislation were proposed to increase the standards of teaching and learning; funding, however, did not necessarily reflect the fervor for reform. Just as legislators failed to look at education reform beyond the immediate future, the process by which reform proposals were drafted reflected haste and a desire for a quick fix (e.g., Spector, 1986).

What was the problem? Why weren't children learning science any better than before? Why were the number of science majors declining at universities? Why were students of all ages, of specific genders, and ethnicities "turned off" by science (e.g., Ballou, 1986; Kincheloe et al., 1992; Lin et al., 1996; Lipson and Tobias, 1991; Pushkin, 1991)?

> The great American experiment in mass higher education has failed completely in the sciences, where we have a small educated elite and an illiterate general public. Our graduate education in science is the best in the world, and contrary to the belief of some, we do not face a future shortage of scientists. However, the rest of our educational system is bad enough to constitute a threat to the ideal of Jeffersonian democracy.... The educational infrastructure must be strengthened to the point where science can be taught gradually, throughout the schools years and beyond. Furthermore, those of us who are professional teachers of science must become better teachers, both by increasing our own mastery of our subjects and by better understanding the difficulties our students have in learning science. (Goodstein, 1992, p. 149)

A phenomenon I sense exists in many university science departments involves the prevalent philosophies of *perpetuation of the species* and *survival of the fittest.* What do these Darwinist philosophies mean?

Many science departments -- be they biology, chemistry, or physics -- appear to believe that the primary purpose for their existence is to produce majors. University faculty are growing old; replacements will be needed someday. Where will those replacements come from? The majors we teach! After all, who better to replace us than our academic offspring?

However, there lies the paradox. What will our academic offspring be like? Quite similar to ourselves, if some had their way. *After all, we worked hard for years to attain the rank, expertise, and success we enjoy. We learned from our academic* *parents, and look how well we turned out. If it's good enough for us, it's good enough for the next generation.* If we see things so clearly, why bother with reform? How obvious does it need to be before we realize how dissatisfied we are with our teaching and curricula? As educators, can we really live with ourselves by blaming it on today's students?

Unfortunately, there are science departments that subscribe to this first philosophy; they are the ideal image of a scientist, and teaching science is no different than being made in our Creator's image. Anything less would seem an affront to science and its hallowed tradition. Science is often looked upon as an apprenticed trade, where process and sequence are the dominant themes. (Pushkin, 1997b, p. 9)

(4) The Impact of Postmodernism on Science Education

> Most of the great advances in science, as well as a host of lesser ones, have come from the creation, development, and application of theories. Thus the study of theories as theories must be central to science education if education appears to approximate real science and to be more than a cabinet full of categories.
>
> Since embedded theories give the most fully developed rational structure to established knowledge, an orderly and rational development of courses and curricula cannot occur until all theories with many of their lines of reasoning are known explicitly. And since in theories one finds the most successful pattern and style of reasoning, the proper teaching of theories can be the major vehicle for teaching the arts and habits of rational thinking and building the associations necessary for lasting memory. (Lewis, 1987, p. 4)

Modernism itself is a reflection of the scientific method, a process "tried and true," where logic and external control are the dominant characteristics. Modernism seeks an *absoluteness* to knowledge; knowledge is looked upon as an experimental variable, as opposed to an evolving phenomenon. Modernism sees science as something universal, a trade that is passed on from generation to generation. Becoming a scientist is bemoaned by the traditionalists; they long for the days of serving apprenticeships with a "name" mentor.

> Since the "truth" claims of science are tied to the methodological imperative, it insists that science must be held immune from the influences of social and historical situations. Science, therefore, is truth and can, for this reason, represent itself by means of its procedures, by which the objects of investigation and apprehended. Hence, the self-criticism of science is conducted within the boundaries of its own normative structures. Further, science insists that only those inducted, by means of training and credentials, into its community are qualified to undertake whatever renovations the scientific project requires. (Aronowitz, 1988, p. viii)

How has this translated to science? Research is often deemed meaningful on the basis of empirical reliability, validity, and generalizability. How has this translated to science education? Research is often deemed meaningful on the same criteria. Education reform is defined as "curricular engineering;" curricula and pedagogy are to be uniform and reproducible.

Consider a debate among science faculty developing a science education program. One faction considers science education an appendage of science; another faction considers it an amalgam of science, teaching, and learning. The former faction believes inquiry is the most superior mode of science learning; the latter faction considers inquiry one of several valuable modes of science learning. The former faction sees the phenomenon of science education in very dualistic terms; the latter faction sees it in more relativistic terms.

Modernism has manifested itself in the "positivistic" paradigm of education research, where all variables should be controlled, learners and teachers are inert samples to be randomized and manipulated for the sake of a null hypothesis, and the research is more important than the researcher or researched. Analysis is a function of a standard logic, where "one size fits all."

> The tradition dictates that the hypotheses and the research procedure must not be altered even if the field experiences encountered suggest such a strategy. All in the name of objective procedure, the results of the empirical research are examined in light of the original theory which generated the hypothesis; the research is confirmed or falsified on the basis of its congruence with the hypothesis. This hypothetico-deductive research procedure, as it is called, posits a discrete sequence of steps with each step influencing the following one -- e.g., formulation of hypothesis, data collection, data analysis, etc. Since the procedure does not allow for the adaption of research procedures to the circumstances encountered in the observation, the inquirer must not look at anything not explicitly anticipated in the original design of the research. For the positivistic researcher to attend to the 'extraneous noise' of the research site is to risk turning into a pillar of salt, that is, to risk the invalidation of the entire project. Of course, the noise of the research consistently turns out to be the source of the clues which grant insight into the mystery, the data which yield the subtle insight into the significance of an educational situation. (Kincheloe, 1991, pp. 54-55)

What is postmodernism? How did it come about? How is it manifested?

Postmodernism is essentially the paradigm of flexibility and breaking from traditional modes that serve only tradition. When classical physics could no longer answer all the questions posed and phenomena observed at the turn of the 19th century, a new perspective was needed; hence the birth of relativity and quantum theory. When conventional structural theory could not explain the formulas and properties of aromatic hydrocarbons, chemists such as Kekulé considered the possibilities of such compounds having ringed structures. When the American curriculum could no longer serve its students with only the classics, educators finally incorporated the sciences. When curricular and pedagogical decisions were made from legislators and agencies, teachers and students rebelled, sharing their dissatisfaction with "top-down" mandates.

Postmodernism is essentially the paradigm of discord with tradition. When qualitative researchers feel threatened by their established colleagues, because their research bears neither hypotheses nor empirical data, they must fight to gain respect and consideration for their work. When terms such as *validity*, *reliability*, *significance*, and *certainty* are used in only a quantitative context, ethnographic and phenomenological researchers struggle to publish, as well as for tenure or promotions. Because of relativity, structural chemistry, and quantum theory, we have learned that knowledge, data, theories, concepts, and validity are both *contextual* and *contingent*. Although there are certain facts that we treat as absolute, what we know is not necessarily absolute; knowledge is always evolving. Modernists see primarily in black-and-white; postmodernists primarily see a spectrum of many colors and shades of grey (Pushkin, 1996c). Even when we discuss students' answers to questions in a science class, we emphasize misconceptions, automatically identifying what they say as wrong; to take something out of context is more of a *pseudoconception*, for it is not entirely wrong (Pushkin, 1996d).

But most importantly, postmodernism is the paradigm of freedom for educators and learners alike. For too long, schools have been bogged down by tradition and inertia. Administrators and educators alike are too resistant to change; likewise, students have become too accustomed to the way things are. A modernist approach to science education is one that treats concepts like factoids, assessment like multiple-choice endurance exercises, and problem solving like mimicry drills. We teach students trivial information and practice mindless exercises; we have lost our purpose in science education.

Science at one time was a field of great excitement and creativity; we've lost that over the past decade or so. Science education has unfortunately reflected this loss. Science has become routine. Teaching science has become routine. Learning science has become routine. Does this imply that we should discard what we are doing completely? No; but this is the time to reflect on what we are doing, and ask ourselves *why are we doing it this way, and do we really like doing it this way?* Change for the sake of change is not what we need. We need purposeful change -- change that will move us closer to what we envision for science education. However, until we truly identify what it is we want in science education, we will neither understand what within our curricula and pedagogy needs reform, nor what that reform should be.

Emancipation is not exclusively external; emancipation needs to come from within first. If we do not have a sense of academic and intellectual freedom, how could we possibly expect our students to have it? We need to be willing to free ourselves from our standard ways of thinking. We need to be open to alternative ideas; whether we agree with them or not, we should at least respect them and encourage their development. We need to create a learning culture of open-mindedness for our students. Students need to learn more than the "right answers;" they need to learn how answers develop, and how answers can be potentially right. A critical thinker is one who sees many sides of a coin, and many shades of grey; how can we expect our students to become critical thinkers when their learning environment fails to nurture critical thinking?

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