From Intuitive Physics to Star Trek:
Large Context Problems (LCP) to enrich the teaching of physics.

From Theory to Practice:
Placing contextual science in the classroom

A monograph by Arthur Stinner

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From Theory to Practice: Placing contextual science in the classroom

I will present a discussion of the need for contextual teaching in science (physics) with emphasis on the large context problem (LCP) approach that was developed at the University of Manitoba. In the Appendix I will place a detailed outline of a series of large context problems (LCP) that I am now preparing, entitled:

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Introduction

The contextual approach to the teaching of physics

In developing a program of contextual science my aims were, first, to liberate teachers from the tyranny of textbooks, and secondly, to humanize the teaching of science by placing it in rich contexts, informed by the nature and history of science. Research in science education shows that students often leave school with a knowledge of isolated, disconnected facts, based on memorization and problem solving ability mostly based on memorizing algorithmic procedures. Textbook-centered teaching also promotes a poor understanding of the nature of science and a spotty knowledge of the history of science (Rigden, 1991).

All this, however, does not suggest the need for a total replacement of textbooks and the abandonment of teaching algorithmic procedures. It only recommends the displacing of textbooks from their conventional central position to one of a good source of reference. Algorithmic procedures should still be taught, not just as an aid to memorizing but rather as an economic way to solve certain important class of problems. Using textbooks as reference only and teaching algorithmic procedures should be more along the lines suggested by Kuhn in providing the understanding of the central problems of physics that he first called exemplars, or model solutions (Kuhn, 1962).

Working with exemplars involves working with instruments in the laboratory and practising problem solving. The well-known exemplars of elementary physics are connected with *the inclined plane*, *the pendulum*, *Atwood's machine*, *the ballistic pendulum*, *the wave-tank*, and more recently, *the electronic air table*. In his *The Structure of Scientific Revolutions* , Kuhn argues that a physics student becomes acquainted with and discovers the fundamental notions of Newtonian dynamics only through the application of these concepts to both problem solutions in the laboratory and on paper. He argues that this is the way students should make “contact with nature”, Students do not learn physics by reading the definitions of *force, mass, instantaneous velocity* , etc. and the memorization of algorithms which are then applied to “type” problems in the textbooks.

According to contextual learning theory, learning occurs only when students (learners) process new information or knowledge in such a way that it makes sense to them in their own frames of reference. This approach to learning and teaching assumes that the mind naturally seeks meaning in context, and that it does so by searching for relationships that make sense and appear useful (Driver, 1989).

Research also shows that presenting major concepts and ideas in science imbedded in context by way of a coherent story is essential in retaining these concepts and ideas. Indeed, if science is taught as a 'fact' without context or a coherent story line, students will try to invent their own. It is arguably a truism that appropriately designed contexts which attract young students' interests often create great motivation to learn science (Kenealy, 1989).

Setting appropriate contexts, however, go beyond serving as a source of motivation. There is strong evidence that we must connect cognitive activity to context, that learning methods imbedded in context are not merely useful; they are essential. In spite of a general agreement about the importance of contexts our textbook-centered teaching in science seems to stubbornly ignore it (Roth, 1993).

The Large Context Problem (LCP)

The superiority of a contextual approach over the conventional textbook-centered teaching in physics became clear to me after designing and successfully using my first contextual setting for a senior physics class in a Canadian (Toronto) high school. What I later came to call the "large context problem" (LCP) approach was originally developed as a response to the discovery that *learning could be well motivated by a context with one unifying central idea capable of capturing the imagination of the students.* The second aim for developing contexts was that the topics, the concepts, and the general content of the textbooks should be covered by the context. What I found was that the questions and problems generated by the context were intrinsically more interesting and less contrived than the corresponding ones found in textbooks.

Early experiences using LCPs

I have discussed the rationale and the design of LCPs, embedded in a rich theoretical background provided by the *contexts of inquiry* in detail elsewhere (Stinner, 1989a, 1989b, 1994); Stinner & Williams, 1993). LCPs are contextual settings that are designed by the teacher in collaboration with students. Each LCP should be so designed that most of the physics for a particular topic would have to be used for the successful completion of the problems suggested by the context. What is so attractive about this kind of setting is that the questions and problems are generated *naturally* by the context and will *include* problems that are given *out of* *context* (in a contrived way) in a textbook for a given topic. Designing contexts on this scale gives the instructor the status of researcher and the student the feeling of participating in an on-going research program.

Indeed, many of the questions and problems generated do not have obvious answers for the student or the instructor. The ability to answer questions and solve problems that do not have textbook answers, using elementary physics only, is very rewarding for both students and teachers. A contextual approach to the teaching of physics may be more time-consuming then the conventional textbook approach. However, the understanding of the student as well as the quality of interaction between the student and the teacher is lifted from an ordinary to a high-grade level. Indeed, solving problems that are naturally generated by a context that attracts the imagination of the student are more likely to make contact with nature than solving contrived problems in text books.

Examples of LCPs that we have developed over the years are: “Physics and the Bionic Man”, “The Physics of Star Trek”, “Physics and the Dam Busters”, “Hitchhiking on an Asteroid”, “Calculating the Age of the Earth and the Sun”, “Pursuing the Ubiquitous Pendulum”, and “Sudden Impact: The Physics of Asteroid/Earth Collisions”(See references).An example of how one can use the contexts of inquiry and the history of science in a major topic is : ‘The Story of Force: From Aristotle to Einstein” (Stinner, 1994 b).

Even a cursory survey of journals like *The Physics Teacher*, will provide the physics teacher with plenty of examples of such contextual settings: “The Physics of the Play Ground”, “The physics of Toys”, “Physics and Skiing”, and historical surveys, like “Is Maxwell’s displacement current a current?”, “Newton’s Thermometry: The role of Radiation” and “The search electromagnetic induction”. These could be easily adapted and transformed into LCPs or investigations using *the concepts of inquiry*. Later I presented general guidelines (See Appendix) for the planning and thedevelopment of large context problems, as can be seen below in the Appendix.

In my science education classes at the University of Manitoba I have had students design LCPs for science in general and physics in particular with notable success and enthusiastic cooperation. Many of these LCPs were later used in physics classes when these students began teaching physics. Can we place LCPs in a central position in existing curricula and teaching practices?

Originally the LCP was placed peripherally to the textbook and the curriculum. I used LCPs mainly to reinforce core material to the extent that time was available. The high school Physics curricula in Canada (in most provinces) at that time generally consisted of a core

Cntent surrounded by “options”. The core and the sequencing of topics was conventional. The options were contexts such as “Solar Energy” and “Motion: Earth and Sky” that I realized could be developed into good LCPs. Unfortunately, the options were generally considered “interesting supplementary material”, and if used at all, discussed only in a hurried manner. Both teachers and students are primarily interested in “covering the material” in preparation for the next level of physics or science course. The mandate to “cover” the material in the curriculum is still with us (Stinner, 1994).

Examples of innovative physics teaching

Innovations in science (physics) teaching all seem to rest on one simple premise: *a better learning experience results from an active engagement of the student.* Many of these innovations can be placed in the following categories: (1) microcomputer–based laboratories, (2) active engagement in lectures, (3) collaborative learning, and (4) structured problem solving. Priscilla Laws and her group at Dickinson College replaces the standard calculus-based physics course; and the virtual physics experimental site. Physics 2000, are good examples of the first approach. Harvard professor of physics , Eric Mazur’s *Peer Instructor*, and the physics education research group at the University of Minnesota have developed “rich context problems” for collaborative learning (Stinner, 1994).

I would also like to mention the work of my colleague Wytze Brouwer at the University of Alberta in improving physics education. The detailed account of the collaborative approach, replacing the conventional lecture-centered teaching of large classes I first year physics, is described in his article (Brower, 1995).

The work of Paul Hewitt is well known. His book *Conceptual Physics* is a successful attempt to present the qualitative aspect of the concepts of elementary physics. This is done through visuals, demonstrations, hands-on, minds-on activities, verbal explanations, and dialogues. There is also a quantitative aspects to this approach but it is kept to a minimum (Hewitt, 1990).

Finally, James Trefil and Robert Hazin’s *The Sciences: An Integrated Approach,* also tries to present the concepts of physics of physics , but uses much more quantitative support. Laws and definitions are given verbally, graphically and pictorially first, but and only then expressed symbolically. It is a nice attempt to balance the quantitative and qualitative aspects of physics, somewhere between the conventional textbook-centered approach and Hewitt’s conceptual approach.

Even a cursory survey of journals like *The Physics Teacher*, will provide the physics instructor with plenty of examples of such contextual settings: “The Physics of the Play Ground”, "The physics of Toys", "Physics and Skiing", and historical surveys, like "Is Maxwell's displacement current a current?", "Newton's Thermometry: The role of Radiation" and "The search for electromagnetic induction". These papers could be easily adapted and transformed into LCPs or investigations using the approach described here.

Local efforts

In the recent physics curriculum reforms in the province of Manitoba contextual teaching and history of science has been incorporated to provide a more humanistic approach to learning physics. In *senior one* students investigate historical models of charge and build and perform experiments with historical apparatus such as the electrophorous. In grade 11 the historical development of the model of light is used as a backdrop to study models in general, as well as laws, and theories explicitly. Several historical case studies (such as the life of Madam Curie (Radioactivity), the history of rock and roll (electromagnetism), and the Doppler effect) have been developed by our teachers which can be implemented in the classroom.

There is also considerable anecdotal support for the success of contextual teaching by my former students who are now classroom teachers. We have one study that measured both academic and attitudinal in a senior high school chemistry class where interactive historical vignettes were introduced. Our conclusion was that academically there was no significant improvement but the attitudes of students toward chemistry measurably improved. We are about to publish these findings.

I am hopeful that the book and the DVD I am now developing will be available by the late spring of 2007. What remains is a systematic testing of contextual using the LCP approach in a high school class. I am looking forward to a large scale study that uses the contextual approach as outlined here, where textbooks are consulted, but not centralized.

Concluding remarks

The foregoing discussion about the role of imagination in science, however, suggests that a fairly radical change from the conventional text book-centered physics teaching is required if we want to teach an authentic science (physics) to future physicists or scientific (physics) literacy to the general public. Granted, the main task of physics educators has always been to prepare young people for physics research and the professions that require a good basic understanding of physics. Today, however, we must go further and ensure that all students leave school with a basic scientific literacy that includes a knowledge of elementary physics. In order to achieve these goals, we have to make our learning contexts richer and more challenging for both the university-bound student who is required to study physics and the student who is looking for general physics literacy. However, providing rich contexts is a necessary but not sufficient condition for successful teaching of authentic science. We must also educate and train young science (physics) teachers to have a good understanding of the nature and history of science and of how students learn science.

Cutting the umbilical chord with textbook-centered teaching will be successful only when teachers of science (physics) have a deep understanding of the *contexts of inquiry* and have a more than cursory acquaintance with the history of science. We should try to convince textbook writers and publishers to write and publish post-Kuhnian text books that pay attention to the requirements of good pedagogy, the importance of contextualizing the teaching of physics, the nature and the history of science.

Idealistically, we want to help students to traverse, what Alfred N. Whitehead referred to in his “The aims of education”, as “the path from romance to precision to generalization” in our teaching of physics (Whitehead, 1929).

TEACHING PHYSICS THROUGH LARGE CONTEXT PROBLEMS

Content of Monograph

CHAPTER 5: THE DESIGN AND IMPLEMENTATION OF THE LARGE CONTEXT PROBLEM (LCP)

The description of the large context problems

From Intuitive Physics to Star Trek:

Large Context Problems (LCP) to enrich the teaching of physics

LCP 1: INTUITIVE PHYSICS AND MOTION

LCP 2: MOTION AND THE PENDULUM

LCP 3: THE PHYSICS OF THE LARGE AND SMALL

LCP 4: WIND ENERGY

LCP 5: THE FLIGHT OF THE SPACE SHUTTLE

LCP 6: SOLAR ENERGY

LCP 7: THE ROTATING SPACE STATION

LCP 8: PHYSICS ON THE MOON

LCP 9: THE AGE OF THE EARTH AND THE SUN

LCP 10: JOURNEY TO MARS

LCP 11: ASTEROID/EARTH COLLISIONS

LCP 12: HITCHHIKING ON AN ASTEROID

LCP 13: THE PHYSICS OF STAR TREK

LCP 14: THOUGHT EXPERIMENTS IN PHYSICS

The content description of the LCPs:

From Intuitive Physics to Star Trek: Large Context Problems (LCP) to enrich the teaching of physics

LCP 1: INTUITIVE PHYSICS AND MOTION
All of us have common sense (intuitive) ideas about motion and forces around us. These ideas can be called personal "theories" of motion based on familiar experiences. We then try to explain motion around us based on these theories. We could refer to this understanding as pre-scientific, intuitive, "personal knowledge". In this LCP we will test and challenge students conceptual understanding of motion. Much of this LCP is based on my articles (see references).

LCP 2: MOTION AND THE PENDULUM
The pendulum did not only play a central role in the development of the kinematics and dynamics in the seventeenth century, but served as a research instrument in the 18th and 19th centuries. We can look at the pendulum as the most successful research instrument to test intuitive understanding of the physics of motion and develop our understanding of the physics of kinematics and dynamics. Its ubiquity is attested to by the modern application of the pendulum to the study chaos and non-linear motion.

This context is based largely on Galileo's ideas, the recent special issues of *Science & Education* "The Pendulum: Scientific, Historical, Philosophical, & Educational Perspectives", and the work of the author and Don Metz (The Ubiquitous Pendulum, *The Physics Teacher*, (2003*)*. Almost all elementary kinematics and dynamics can be taught here and/or reinforced. Much of this LCP is based on my articles on the pendulum (see references).

LCP 3: THE PHYSICS OF THE LARGE AND SMALL
The elementary physics of materials and of mechanics determine the limits of structures and the motion bodies are capable of. The physical principles of strengths of materials goes back to Galileo, and the dynamics of motion we need to apply is based on an elementary understanding of Newtonian mechanics, and the mathematics of scaling required depends only on an elementary understanding of ratio and proportionality. The physics of micro, meso, and macrorobots will be discussed. Finally, the main ideas developed here are intimately connected to architecture, robotics and biology and will be used in the later chapters. It is hard to imagine a more motivating large context to teach the foundations of statics and dynamics with a strong link to the world around us.

This context is based on three sources: Galileo's "Two New Sciences", first published in 1640, G.B.S. Haldane's celebrated article "On Being the Right Size", published in 1928; Mel Siegel's (a robotics research professor) recent comprehensive summary of robotics "When Physics Rules Robotics"; and the author's updated version of the article "Physics and the Bionic Man" published 25 years ago in *The Physics Teacher* and *New Scientist.* This context provides an excellent opportunity to learn to think in proportionality statements, and become familiar with scaling.

LCP 4: WIND ENERGY
We hear a great deal about microrobots and nanotechnology but not about macrorobots. Good examples of macrorobots are radio telescopes, oil tankers and the International Space Station. These are all beyond human scale. The macrorobots we will discuss are the Giant Wind Turbines (GWT) and later the giant solar furnace in Souther France. GSF. The GWT produce 1 or more megawatts of electric power, and the GSF is represented by the largest one in the world, the Louis Pyrenees solar furnace in France, . The GWT is truly a viable energy production machine but the GSF is really a giant research instrument. However, the physics and the technology in discussing this giant research instrument can be used to design solar collectors for household and the design of robots on the human scale. We can also discuss the physics of voltaic cells and solar energy collection on the meso and macro scales. and those generated by the GWT lead to a discussion of the physics of wind energy, electric power production, electric storage and electric circuits.

LCP 5: THE FLIGHT OF THE SPACE SHUTTLE
The Space Shuttle has been very much in the news recently and most students have seen pictures of the shape of the trajectory. Many are also aware of the fact that the successful descent of the Orbiter depends on using the drag of the atmosphere. However, the physics of the flight of the Space Shuttle, the ascent and the subsequent descent of the Orbiter, is often shrouded in mystery and misconceptions. Textbooks for introductory college physics generally do discuss the rocket equation and show how to calculate the period of the Orbiter, but the physics of the trajectory of the Shuttle is seldom presented.This LCP will provide the background for a sufficiently comprehensive description of the physics of the Space Shuttle launch and descent. I have used actual data for the launch, taken from NASA sources on the Internet, for our calculations and the production of the graphs.

LCP 6: SOLAR ENERGY
The LCP discusses the general physics of solar energy collection. This main concern is the operation of the world's largest parabolic solar collector in the Pyrenees in Southern France. Ther is much information on the internet with sufficient technical detail to allow the setting for an investigation that involves a great deal of students' knowledge of physics and, with some guidance, can lead to an asking of a series of questions that lead to problems and experimentation that go beyond the textbook. The Mont-Louis solar furnace in the Pyrenees is still the largest in the world**.** The questions generated lead to the discussion of electricity, magnetism, mechanical energy, radiation, optics, wave motion, thermodynamics, solar energy, thermonuclear reactions, and BB radiation,

LCP 7: THE ROTATING SPACE STATION
The design and the physics of a rotating space station is presented. Description and the physics of the RSS, a la *2001: Space Odyssey*. A tear-level system for training astronauts to go to the Moon and Mars will be discussed..This context is based on NASA information from the Internet, and the author's original unpublished LCP that he designed and uses in his physics education methods classes. The physics that is part of this context is dynamics and gravitational theory.

LCP 8: PHYSICS ON THE MOON:
The physics of low gravity environment is investigated and the physics of living on the Moon discussed. Structures, mobility, astronomic observations, Olympic games, etc are topics investigated. Robots for the low gravity environment are suggested and the physics of motion This context is based on NASA information from the Internet, and the author's unpublished LCP that he uses in his physics education methods classes. The physics involved is elementary kinematics and dynamics, the strength of material discussed in LCP1.

LCP 9: THE AGE OF THE EARTH AND THE SUN
We will review the main attempts made to calculate the age of the earth and the sun, beginning with Newton's thought experiment and ending with Hans Bethe's thermonuclear model of the sun's energy. In Part One special attention is paid to the protracted debate about the age of the earth in the second half of the nineteenth century that involved Kelvin and Helmholtz. Part I will terminate with a brief mention of the radioactive / nuclear theories being developed just prior to the death of Kelvin in 1907. Part II will look into 20th century explanations and dating techniques, paying special attention to the thermonuclear model first proposed by Hans Bethe in the late 1930s.

For both parts the results of the calculations are given in the main text but details can be found in the boxes that will allow teachers and students to solve novel problems and generate interesting questions for discussion. SI units will be used throughout, but sometimes it may be expedient to mention the original units used (as in the case of Kelvin's calculations in his celebrated paper of 1862 "On the Secular Cooling of the Earth"). Much of the material is based on my article written published in *Physics Education* in 2002.

LCP 10: JOURNEY TO MARS: THE PHYSICS OF TRAVELLING TO THE RED PLANET
The history of the importance of Mars to the understanding the solar system. Several scenarios to travel to the red planet will be described and the physics of the journey explained. An interactive computer program will allow students to plan their own journey. Elementary planetary dynamics will be discussed: including Kepler's laws, The *Vis-Viva* equation and elementary orbital dynamics. Much of the . Much of the material is based on the article written with John Begoray and published in *The Physics Education,* in 2002.

LCP 11: ASTEROID/EARTH COLLISIONS
The physics of asteroid/Earth collisions will be discussed. The physics of a simple computer model for "impact scenarios" will be developed and several famous collisions (Tunguska, Yucatan) presented in detail. The energy of the recent Tsunami will be compared to an asteroid collision of average size. Much of the material is based on the article written with Don Metz and published in *The Physics Teacher*. in 2003.

LCP 12: HITCHHIKING ON AN ASTEROID.
The NASA project called NEAR visit to the asteroid Eros is discussed in detail. We will develop an interactive model for studying this mission along the lines of the mission to Mars model available to students. Much of the material is based on the article written with Don Metz and published in *Physics in Canada*. in 2003.

LCP 13: THE PHYSICS OF STAR TREK

The study of motion in the three regions of physics: speed of less than 10% the speed of light (Newtonian), speeds greater than 10% but less than the speed of light (Einsteinian), and speeds greater than the speed of light (superluminal, or tachyon-like). Several historical calculations of the age of the Earth and the Sun, from Bishop Usher, Newton, Helmholtz, Lord Kelvin to using modern radioactive dating will be discussed.

The background to this context is based on the research done for the article "Physics of Star Trek", and published by *New Scientist* in 1981. The article was written by the author and Ian Winchester. The physics for this context involves Newtonian dynamics and gravitation theory and the well known consequences of the special theory of relativity. Much of the material is based on the article written with Ian Winchester and published in the *New Scientist* in 1981..

LCP 14: THOUGHT EXPERIMENTS IN PHYSICS

"How far can we go in understanding the world with rational thought alone?"

This is Aristotle's question that was later more thoroughly explored by Galileo, Newton, and Einstein. The concern here is discussion of thought experiments containe the article:

Stinner, A. and Metz, D. (2006). Thought Experiments, Einstein, and Physics Education. *Physics in Canada*, pp. 27-37. (Nov./Dec. 2006).

(The article can be downloaded from my website)

Guidelines for Writing LCPs

1. Map out a context with one unifying central idea that is deemed important in science *and* is likely to capture the imagination of the student.
2. Provide the student with experiences that can be related to his/her everyday world as well as being simply and effectively explained by scientists' science but at a level that "makes sense" to the student.
3. Invent a "story line" (may be historical) that will dramatize and highlight the main idea. Identify an important event associated with a person or persons and find binary opposites, or conflicting characters or events (Egan, 1986) that may be appropriate to include in the story.
4. Ensure that the major ideas, concepts and problems of the topic are generated by the context naturally; that it will include those the student would learn piece-meal in a conventional textbook approach.
5. Secure the path from romance to precision to generalization (Whitehead, 1929). This is best accomplished by showing the student that
    a. problem situations come out of the context and are intrinsically interesting;
    b. that concepts are diversely connected, within the setting of the story as well as with present-day science and technology;
    c. there is room for individual extension and generalization of ideas, problems and conclusions.
6. Map out and design the context, ideally in cooperation with students, where you as the teacher assume the role of the research-leader and the student becomes part of an on-going research program.
7. Resolve the conflict that was generated by the context and find connections between the ideas and concepts discussed with the corresponding ones of today.

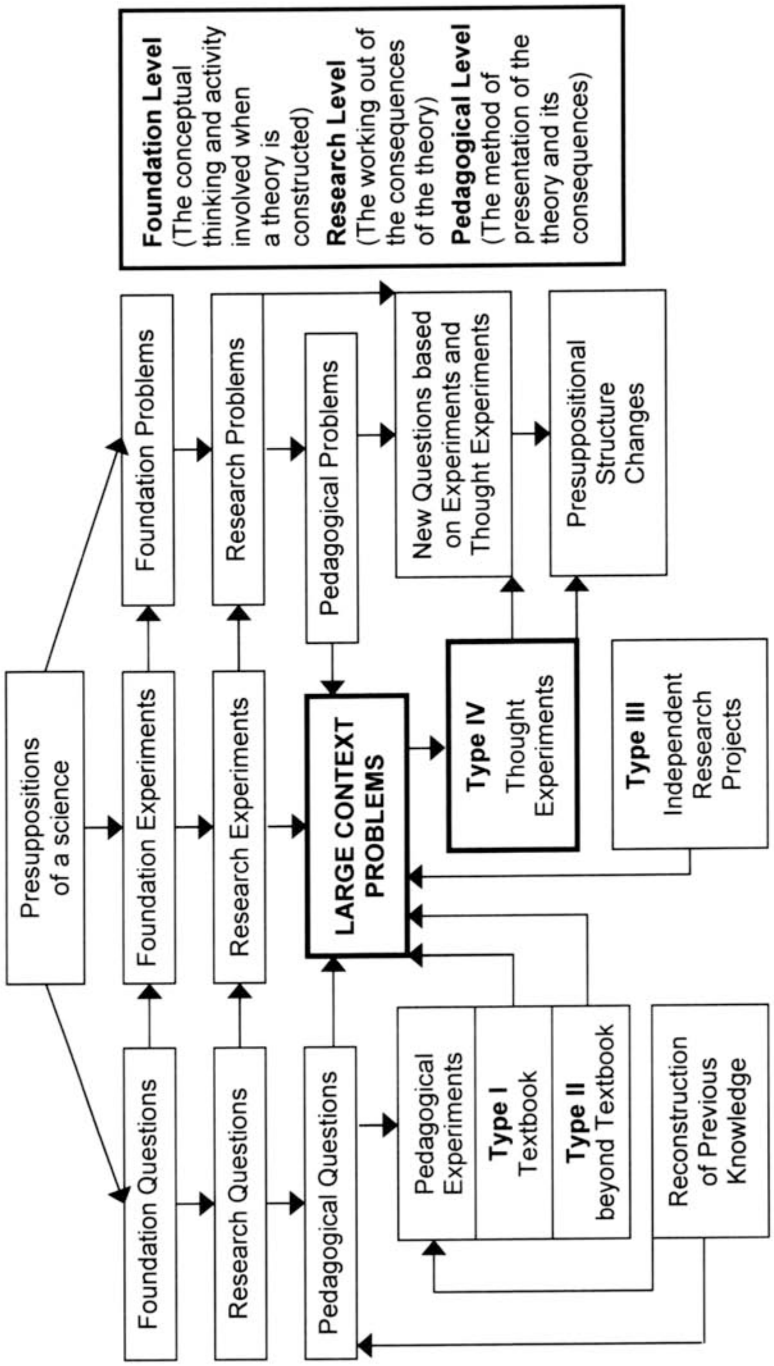

Figure 1: Levels of Investigation for Scientific Inquiry

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CHAPTER 1: THE IMPORTANCE OF CONTEXT

Learning occurs only when students (learners) process new information or knowledge in such a way that it makes sense to them in their own frames of reference. This approach to learning and teaching assumes that the mind naturally seeks meaning in context, and that it does so by searching for relationships that make sense and appear useful

(Driver, 1989).

Students learn best–and retain what they have learned–when (1) they are interested in the subject matter and (2) concepts are applied to the context of the students' own lives.

(ATEEC Fellows 2000).

When one leafs through any high school physics textbook the contextlessness of the material presented is easily apparent. Most textbooks portray science in a highly convergent, rational manner that overwhelm the reader with a claim of authority and truth. ...By implication, such texts convey the message that the context of the inquiry is seldom essential to the inquiry itself. Yet, paradoxically, one of the goals of pedagogy is to draw the content of the lesson into the life-world of the student and to accomplish this, context must be provided.

(Martin and Brouwer, p. 707).

Introduction

Some years ago a local radio station called me by telephone as I was entering my office early in the morning. After identifying himself, the gentleman asked me about the results of a nation-wide science literacy test, just publicized in the newspapers. I freely admitted that I had not read the paper that morning. "Dr. Stinner are you not surprised that 13% of Canadians believe that the sun revolves around the earth?" the voice asked. My reply was immediate: "Not really". The voice kept pressing: "As a science educator are you not concerned?" Again I replied: " Not especially".

Clearly, that was not the response expected from me. After a brief pause I asked: "Do <u>you</u> believe that the sun revolves around the earth?". There was a long silence, followed by a defensive: "No, of course not." It was clear that my next question I was equally unexpected: "What <u>evidence</u> can you give me for believing that the earth rotates around the sun?" The response came slowly and with hesitation: "Well, my science teacher taught me that scientific fact in junior high school." Since he was unable to provide me with appropriate evidence for supporting that "scientific fact" I gently implied that he, too, was scientifically illiterate. Our conversation ended quickly.

This anecdote illustrates what Alfred North Whitehead said over 70 years ago: *In training the young to activity of thought, above all things we must beware of what I will call "inert ideas"-that is to say, ideas that are merely received into the mind without being utilized, or tested, or thrown into fresh combinations.*

In our science classes the textbook plays a dominant role and dictates both what we teach and how we teach it. In 1983 the science educator Yager summarized research on science textbooks. His conclusions are as valid today as they were then. He stated that the most significant decision science teachers make is the choice of a textbook. Yager argued that textbooks imprison science teachers in a belief that the instructional sequence of assign, recite, and test is guaranteed to produce knowledge. He went on to emphasize that direct experience is almost never offered, and laboratory work, if it occurs at all, is of the deductive-verification type. He claimed that high reliance on textbooks does not seem to produce scientifically and technologically literate graduates. Yager concluded cryptically that the status of science education can be summarized in a single word: textbooks

The contextual approach

According to contextual learning theory, learning occurs only when students (learners) process new information or knowledge in such a way that it makes sense to them in their own frames of reference. This approach to learning and teaching assumes that the mind naturally seeks meaning in context, and that it does so by searching for relationships that make sense and appear useful.

Research also shows that presenting major concepts and ideas in science imbedded in context by way of a coherent story is essential in retaining these concepts and ideas. Indeed, if science is taught as a ‘fact’ without context or a coherent story line, students will try to invent their own. It is arguably a truism that appropriately designed contexts which attract young students' interests often create great motivation to learn science. We will see later that the ‘large context problem’ approach for the teaching of physics was originally developed as a response to the discovery that

> *learning could be well motivated by a context with one unifying central idea capable of capturing the imagination of the students. .*

Setting appropriate contexts, however, go beyond serving as a source of motivation. There is strong evidence that we must connect cognitive activity to context, that learning methods imbedded in context are not merely useful; they are essential. In spite of a general agreement about the importance of contexts our textbook-centered teaching in science seems to stubbornly ignore it.

A general problem, however, emerges whenever teachers try to escape from textbook-and lecture-centered teaching to teaching science by way of contexts that students find attractive: *In order to answer the questions and solve the problems generated by a context (to get off the ground, to make a start), students already have to have mastered part of the content.*

The interaction between content and context, then, presents a central pedagogical problem. We could summarize the problem this way:

> *To motivate students to acquire content knowledge we set contexts that attract them. However, students often cannot deal with the questions and the problems that the context generates unless they already have some content knowledge.*

The traditional way out of this dilemma is to present the organized content knowledge of science in early as ‘early years science’, certainly by the time students reach ‘middle years science’. Such concepts and conceptions as energy and energy transformations, photosynthesis, atomic structure, DNA, and kinetic molecular theory are often introduced as middle years (grades 5-8). However, young students are not ready developmentally for these concepts of organized science content knowledge. Pines and West (1986) call this knowledge formal knowledge (someone else's interpretation of the world, someone else's reality) it is also known as "scientific knowledge", "school science", "curricula knowledge" and so on. This knowledge differs from children's knowledge that they call, following Vygotsky, "spontaneous knowledge" (p. 586). According to Pines and West "...formal instruction cannot simply be poured into the child's head or inscribed on a *tabula rasa*, but rather formal instruction interacts with the wealth of existent knowledge"

(p. 587).

Our mandate as science teachers then is to try to ease the passage of children from early "common sense" apprehension of the world to a comprehension of organized scientific knowledge. Confronting students with the finished products of formal science too early and too suddenly produces a discontinuity that may alienate students. This alienation then produces two distinct and incommensurate views of science in the minds of the students, namely ‘school science’ and ‘common sense’ science.

One plausible approach to achieve successfully the passage from early years common sense understanding of science to a scientist's understanding in the senior years might be early introduction to science by way of stories and contextual teaching that attracts students' interest. Moreover, contemporary issues of interest to students should be included that make connection with their personal experiences (Bloom, 1990; Martin and Brouwer, 1993). Learning science involves both personal and social processes (Driver, 1994). Therefore, we must set contexts that attract students and allow them through on-going personal reflection and verbal and written discourse to become "socialized to a greater and lesser extent into the practices of the scientific community" (Driver *et al*, p. 8). Such contexts should provide opportunities for the various learning styles, personal reflections and problem solving as well as participation in group discussions and experiential and experimental activities. It is through engagement on the personal as well as social levels that the early and middle years student will be able to make connections with other contexts and develop "personal schemata" for gradual decontextualizing and generalizing scientific knowledge.

Arguing along similar lines Selley (1989) advocates the abolition of the gulf between scientific knowledge and "common sense" beliefs by "developing the student's personal explanatory model gradually, through clarification, comparison with data and evaluation against suggested improvements" (p. 29). Martin et al (1990) recommend that students be allowed to explore the personal dimension of science, and this may "imply that greater emphasis be placed on the development of an experimental basis rather than in the formal development of 'scientific facts and ideas'"(p. 552).

Strube (1989) claims that texts in science may not be meeting their purposes to instruct, due to their over-riding concern to *'inform'*, and therefore do not develop a language of inquiry appropriate to the student. This tendency of text to 'inform' only is especially damaging in the early and middle years since there is no provision made for the student to explore problems that are interesting, nontrivial and personally relevant to the learner (Wong, 1993). Glassen and Lalik (1993) have used what they call a *Language-Oriented Learning Cycle* for middle school science that has an exploration, clarification and elaboration cycle. This cycle uses verbal argumentation, among other approaches, that allow students and teachers to negotiate the meaning of scientific explanations. Howe and Vasu (1989) show that by using verbal arguments and narrative passages subjects are able to form mental images that enable them to improve recall.

The senior years: toward a comprehension of organized scientific knowledge

The senior years student should go further and be able to generalize and make connections between contexts and organized scientific knowledge. These connections should be made by engaging the student in discussion, asking for verbal arguments that involve personal knowledge as well as the language of decontextualized science. For example, the senior physics student should be able to give a well-reasoned, well-written explanation of the notion of 'weightlessness' inside the orbiting space shuttle, using both personal insights and the symbolic language of physics. It is clear, however, that students will not learn how to provide such an explanation (and will, indeed, be reluctant to do so) unless teachers stress verbal argumentation and "assign scientific explanations a prominent place in science classrooms..."(Dagher and Cossman, 1992).

This act of generalization, however, often amounts to an epistemological break with common sense and the everyday world. For example, physics teachers try to persuade students to escape from seeing the world of motion in Aristotelian terms into an understanding of motion in Newtonian terms. As physics teachers well know, such a break is difficult, and can be compared to a paradigm shift.

The notion of spiral curriculum, whereby concepts such as force, energy and density are revisited as the student progresses through school must now also be rethought.

Clearly, such concepts must be revisited *in progressively richer contexts and higher levels of sophistication,* including verbal, qualitative accounts of phenomena as well as using quantitative, experimental and instrumental accounts. The students' accounts can involve symbolic generalizations, using mathematical language to describe explanatory models. But these formal generalizations must be based on earlier contextually-established personal schemata.

The so-called *processes of science*, too, are generally presented in a decontextualized fashion. Most curriculum documents place great emphasis on these processes; they are identified (observing, experimenting, predicting, explaining, etc) and then applied across domains of study and later evaluated in themselves. This emphasis is based on the common conceptualization of science as comprising, in part, a set of process skills that can be taught more or less independently of content. Millar and Driver (1987), however, point out that such an emphasis on science processes "reflects both an inadequate analysis of the nature of the scientific enterprise and an inappropriate view of learning" (p. 36).

Our goal then is to postpone the full, formal, decontextualized imparting of organized science content, or "scientists' science", until the students are able to demonstrate a readiness for it. For example, teachers should not go from an Aristotelian understanding of force and motion to stating Newton's second law of motion and teaching students to solve "type" problems by way of algorithms. Rather, several steps should precede the formal presentation of the law, involving progressively richer contexts in which motion is investigated. Teachers can assess students' level of readiness for "scientists' science" by identifying their "personal schemata", or what could be called *decontextualized scientific knowledge on the personal level*. However, students must be able to make these schemata explicit by clearly describing phenomena and generalizing across contexts, but expressed in their own words.

Finally, students should be able to differentiate between common sense understanding and the scientific representation of phenomena. They should be able to recognize the adequacy of the common sense view in certain situations, but be able to provide a scientific explanation based on the relationship of theory and evidence.

Our aim then should be to have students say, when they finally encounter such products of organized scientific knowledge as *photosynthesis, Newton's second law* or *the law of definite proportions*: "I understand, it makes sense", or "I remember: this is like...", or even: "Of course, how could it be otherwise?"

"Islands of excellence"

There have been many "islands of excellence" since about 1970 where contextual science teaching has taken place, from early years to the university. All of these are, arguably, rooted in John Dewey's work, who can be considered the father of contextual learning. Dewey described contextual learning when he discussed project-based learning. Educators were to design contextual group activities in which students worked together, as they would in the work place, to be engaged in problem solving. "He emphasized the social aspects of learning and viewed schools as places where students could practice democracy and have opportunities to work together to identify problems" (Daniels & Bizar, 1998). Projects that make connections between curriculum and the work place have been, "…a time proven approach for providing rigorous, relevant, contextual, applied learning in a manner consistent with how learning takes place in the adult world and is also compatible with how the brain learns more efficiently" (Blank & Harwell, 2001).

In early years, science is generally taught contextually, almost by definition. Unfortunately, most early years teachers lack the content knowledge and hence the self-confidence to set contexts that engage students meaningfully. In middle years, students encounter their first hurdle and often loose their enthusiasm for engagement, even if they had a knowledgeable and enthusiastic teacher. The hurdle is the sudden transition from contextual learning to the need for memorizing definitions in science. There is, however, one more hurdle in the first and second year of senior science that discourages students to study science. This formidable hurdle comes in the form of the sudden decontextualized symbolic and mathematical representation of science, especially of physics**.** Unfortunately, too few students manage to overcome these two hurdles.

The following are examples of good contextual science teaching, from middle years to university, since the late 1970s.

In 1977, Poal Thomsen promoted an early chemistry-physics combination in the style of the Danish "Ask-Nature" project. The main aims of this approach were to, first, go beyond only "helping students to a better understanding of what they had already studied in their textbook", and, second, to “teach students to formulate and solve practical problems”.

The late New Zealand physics educator Roger Osborne in his widely read research *Children's Science*, especially the article in the *Physics Teacher* (1981) “Children’s Dynamics”, went further and argued for introducing basic ideas of dynamics at an early age. He believed that without teaching physics early, pupils will develop what he calls their *gut* and *lay dynamics* in ways which are inflexible, limited and inappropriate for the subsequent learning of "physicists' dynamics". He sums up his argument this way:

> *To argue that the teaching of dynamics should begin early is not, however, to argue for the teaching of physicists' dynamics. Rather, the teaching of dynamics from age 5 to 15 should help develop, challenge, and extend gut and lay dynamics in such ways that it helps make better sense of the world and in such ways that the formalized alternative conceptions provided in the senior high school will find a meaningful and valued place. What is required is a smorgasbord of experiences and debate which challenge and modify gut dynamics, as well as clarify language and the purpose of language...the experiences and discussion should provide seeds of alternative conceptions <u>upon which the later teaching of physicists' dynamics can be firmly based</u>* (Osborne, 1984).

Osborne describes the inadequacy of conventional classroom teaching graphically:

Gut dynamics enables one to play hockey, lay dynamics one to talk about Star Wars, while physicist's dynamics enables one to do physics assignments. There is no problem! (p. 506)

What is worrying to physics educators, therefore, is that a high percentage of students, even though they can solve fairly sophisticated physics problems, still operate with gut and lay physics ideas in everyday life.

The noted university physics teacher A.P. French echoes these ideas and referring to the broader aim of teaching scientific literacy says:

> *Probably nothing significant can be done about that (scientific literacy) until we find more effective methods for awakening scientific interest in students at an early age and keeping them interested instead of alienating them*"
> (French, 1986).

How then should we teach such concepts and conceptions as density, Ohm's law, Archimedes' law of flotation, pressure, motion and forces? Physics teachers generally assume that Piaget clearly showed that most of these notions cannot be taught to pre-formal thinkers. Inspite of this accepted dictum I believe that Haber-Shaim's recommendations, the Danish "Ask-Nature" project, and Osborne's approaches to teach science to children is the direction to go. There is indeed solid post-Piagetian constructivist research that gives these approaches good research backing. According to R. Driver, today's constructivists see learning as an adaptive process in which the learners' conceptual schemes are progressively reconstructed in keeping with a wider range of experiences. Like in the Piagetian view, knowledge grows through a process of equilibration between knowledge schemes and new experiences. Unlike in the Piagetian view, however, this new perspective emphasizes the development of domain-specific knowledge structures, and does not focus on the development of general logical capabilities.

We should remember that Piaget was a cognitive scientist and that his findings only inform educators, they are not presented as learning theories.

Moreover, such research as Osborne's *Children's Dynamics* suggests that children may progress in their understanding of concepts by way of intermediate notions that, although pre-scientific, are necessary precursor to scientific understanding. Driver suggests that ways to guide concept accommodation include, later to be referred to, in what we will call "contextual activities", *discrepant events, sequencing of carefully designed activities, encouraging peer group discussions, using bridging analogies, providing an alternative theory to fit evidence, computer-based programs,* and *the designing of multi-media programs.*

Contemporary contextual approaches

At the beginning of the new century we find a number of excellent approaches that are contextual and /or historical, a continuation of the “islands of excellence” of previous years. These innovations in science teaching all seem to rest on one basic premise, promoted by John Dewey over fifty years ago: *a better learning experience results from the active engagement of the* student.

The American science educator Michael Crawford has designed an approach he calls “Teaching Contextually” to go beyond “...the goals of the majority of teachers ...to cover the curriculum and meet the needs of an assessment”. To teach middle school science he uses what he calls *contextual teaching strategies:* relating, experiencing, applying, cooperating, and transferring, REACT. Relating is “Learning in the context of life experience”; Experiencing is “Learning in the context of exploration”; Applying is :”Learning when knowledge is presented within the context of its use”; Cooperating is: “Learning through the context of interpersonal communication, sharing, etc.; and Transferring is “Learning by using knowledge in a new context or situation”.

Crawford regards relating “the most powerful teaching strategy”. He says that students often experience “felt meaning” which induce both the “aha” sensation that often accompanies insight as well as a the more subtle response, a milder reaction which elicits the comment: “Oh, that makes sense.”

Crawford’s *contextual teaching strategies* are clearly more relevant to prepare students for a contextual learning approach than the conventional “science processes” are. We will discuss in detail in the next chapter the activities that are context-relating and context-anticipating.

On the high school and college level, many of these innovations can be placed in the following categories: (1) microcomputer-based laboratories, (2) active engagement in lectures, (3) collaborative learning, and (4) structured problem solving. Priscilla Laws and her group at Dickinson College *Workshop Physics* replaced the standard calculus-based physics course. Their web-based virtual physics experimental site, Physics 2000, is a good example of the first approach. Harvard professor of physics, Eric Mazur’s *Peer Instructor*; and the physics education research group at the University of Minnesota have developed, what they call "rich context problems" for collaborative learning. The last approach is used by the University of Washington Physics Education Group who have developed a series of exercises, based on their research, to help students with conceptual difficulties.

Tong Shiu-sing of the Department of Physics of the Chinese University of Hong Kong, has developed a contextual approach to teach introductory physics. His approach is very relevant to this work. He describes the requirements for good contexts this way:

> *Contextual examples should be interesting and familiar to students. The examples are best easily observed in real life, or are widely reported, like social issues, or examples related to students' lives.*
>
> - *Good contextual examples should allow students to observe clearly and concretely the physical phenomena to be learned in an unambiguous manner. Situations that are too complicated, or unrealistic explanations that may easily misled students should be avoided whenever possible.*

- Students should have the opportunity to make use of their knowledge in physics to solve certain problems inside a context. If possible, the context should provide some real data for students to do quantitative analysis, through which they can understand the underlying physical principles, and then move on to solve realistic problems that are related to life or society. Students can participate in a learning activity to obtain the data from a real environment, or perform the analysis and exploration with computer digital videos or data provided by the teacher.

We will see later that these guidelines are very similar to those that will be described for the design of a large context problem (LCP). In fact his "Contextual Physics in Ocean Park" web site could be called a LCP.

In Canada, the work done by my colleague Wytze Brouwer at the University of Alberta in improving physics education must be mentioned. The detailed account of his collaborative approach, replacing the conventional lecture-centered teaching of large classes in first year physics, is well described in (Brouwer, 1995).

As far as textbooks are concerned, we are seeing a shift toward recognizing the importance of imbedding teaching in appropriate contexts, as well as paying serious attention to the research in conceptual development by science educators. This research clearly shows that students are able to solve problems on physics tests with inadequate understanding of the concepts involved. (Hestenes, 1992, Brouwer, 1995), There are also textbooks that incorporate the history of science in more effective ways than just placing entertaining vignettes in the text (Lawrence, 1996).

The work of Paul Hewitt is well known among physics educators and is much discussed. His book *Conceptual Physics* is a successful attempt to present the qualitative aspects of concepts in physics. This is done through visuals, demonstrations, hands-on (minds-on) activities, verbal explanations and dialogues. There is a quantitative aspect to this approach, but the presentation of "formulas" is kept to a minimum.

James Trefil and Robert Hazen's *The Sciences: An Integrated Approach,* tries to present the concept of physics qualitatively, as Hewitt does, but uses much more quantitative support. Laws and definitions are given verbally, graphically and pictorially first, and only then expressed symbolically. It is a nice attempt to balance the quantitative and qualitative aspects of physics, somewhere between the conventional textbook and Hewitt's book.

What is promising in our quest to liberate ourselves from the tyranny of the conventional lecture and text book-centered teaching is a major development in the US to transforming introductory physics teaching. A good example of this is the work done at North Carolina University, headed by Lairie E. McNeil of the Physics and Astronomy department. McNeil begins her long, comprehensive report by saying that:

> *Traditional physics instruction, as practiced in most physics departments today, involves the presentation of the course material in a standard lecture, with the concepts organized as fully-formulated generalizations that are applied to a few special cases. The students act as passive absorbers of the material and are not required during the lecture to engage intellectually with the ideas being presented. This traditional method is sometimes called the "transmissionist" or "broadcast" mode of teaching.*

In other words, she says, "What we teach is not what they learn".

As a result of these findings, McNeil advocates a departure from the traditional textbook and lecture-centered teaching to a template for new courses. This template calls for interactive lecturing, using electronic response systems, interactive lecture demonstrations, “Just-in-Time Teaching (pedagogical strategy developed to allow instructors to adapt to their lectures to specific learning difficulties and better interaction among students and instructors, the use of Java applets, promote group problem solving, etc. The group is promoting team teaching, better lag/lecture coordination, in short there is a place for engagement and contextualization of physics.

Ideally, we want to help students to traverse with more ease and enthusiasm, what Alfred N. Whitehead referred to, in his “The aims of education”, as “the path from romance to precision to generalization” in our teaching of physics (Whitehead, 1967). Whitehead identifies three different stages or rhythms in educational methodology that he thought happen in tandem and in rotation. He calls these rhythms *romance*, *precision,* and *generalization*. In *romance* stage , the teacher needs to awake the sense of wonder and curiosity in a student's mind. This is the setting of engaging contexts from which questions arise naturally. The attempt to answer these questions then leads to the next stage: *precision.* This is the stage where quantification takes place. The student now studies the principles, definitions, formulae, rules, that develop a thorough knowledge of a discipline or topic. In the third stage, students move into the realm of *generalization*. Here the student makes diverse connections, uses applications, and achieves full, mature usage of the material and ideas of the discipline. Unfortunately, in our conventional textbook-centered teaching, we generally start at the *precision*.stage. Only a few students are able to find “romance” with the quantification requirements of this stage. Consequently most students do not reach the generalization stage.

Cutting the umbilical chord with conventional textbook and lecture-centered teaching will be successful only when textbook writers and teachers of science (physics) have a deep understanding of the *qualitative/quantitative* requirements of good physics teaching and how students learn concepts in physics. This is a necessary but not sufficient requirement for good science teaching. I believe that teachers and textbook writers must also have more than a cursory acquaintance with the history of science and the nature of science. All of these fine attempts mentioned to rise above the conventional textbook-centered, lecture-centered teaching of science (physics), need to explicitly incorporate the history and the nature of science. This will be our mandate for describing the LCP approach in the following chapters.

CHAPTER 2: THE PHYSICS CURRICULUM

> *When compared to teacher effectiveness, student ability, time on task, and the many other things that influence learning, curriculum does not appear to be an important factor.*
> (Arnold Arons, physicist and noted physics educator)

> *The measure of scientific literacy is the measure of cultural awareness. The traditional science curriculum leaves students foreigners in their own culture. A problem in bringing about the essential reform of science teaching is that there are too many scientists that are scientifically illiterate and too few philosophers, sociologists, and historians of science and technology who are interested in pre-college science education.*
> (Paul Dehart Hurd, 1987)

> *Good teachers can rescue the worst curriculum, and bad teachers can kill the best.*
> (Anon.).

Introduction

In an ideal world, the teaching of science would be guided by a curriculum, based on sound pedagogical principles and motivating activities in the classroom; the teacher would implement it in an effective way, and the student would experience and learn the science described in the guide. In the real world, however, that is seldom the case. There are many reasons for the breakdown of this ideal sequence. Curriculum planners may fall short in their planning and produce a curriculum that is in part, or in whole, impossible to implement. The teacher may be unable or unwilling to implement some, or all aspects of the curriculum. Finally, given the range of individual differences among students, it is unrealistic to expect to design a curriculum that will meet the needs and interests of all students over the life of the curriculum guide. As a result, teachers often find it necessary to adapt the curriculum to specific students or classes.

An official curriculum is usually contained in a curriculum guide or a written course of study. Curriculum guides range in specificity from a simple list of goals and objectives which leaves the teacher to determine teaching strategies to a highly prescriptive document specifying behavioural objectives, instructional procedures, and methods of evaluating student achievement. The trend now is away from a highly prescriptive curricula and in the direction of more general goals and objectives accompanied by suggested teaching strategies and activities.

The aim of this study is to present a guide to deliver a well designed curriculum in science (physics) that will make science more meaningful and interesting to students while relieving much of the crowding of the present curriculum. This proposal is that a central theme in the science curriculum and science content knowledge be integrated into a matrix of contextual science activities, using appropriate strategies to deal with the questions, problems and research suggested by these activities. To prepare the way for the discussion of this contextual approach, a brief history of physics teaching will be given, followed by a discussion of the components of a science curriculum. Since the attainment of scientific literacy (SL) is the aim of all science curricula, we will describe the components of SL and the accompanying components of the nature of science (NOS) .

We will begin with a brief survey of the main benchmarks of physics education since the end of the second World War. This brief survey will set the stage for discussing the requirements for any science curriculum, followed by a template for scientific literacy and the nature of science. The response of two provincial physics curricula to the PAN-Canadian science document will be given.

A brief history of physics teaching

After the World War II, the most important objectives in designing physics curricula were:

1. Training in the *scientific method* - both for use in problem solving and in developing an “attitude in “criticalmindedness”,

2. The inculcation of scientific attitudes - leading to a questioning of magic and rejection of mysticism and animism,

3. Developing an interest in the world and in socially significant problems.

There was then, and still is, a wide-spread and pervasive belief that scientists use a specifiable and teachable method in going from observation to establishing laws and theories, namely the *scientific method*. The full explication of a specifiable scientific method that guaranteed success and can be taught is rooted in Karl Pearson’s picture of scientific thinking (Stinner, 1992). Pearson was a famous statistician and his understanding of scientific thinking is imbedded in a well-articulated statement of method in his influential book *The Grammar of Science*, first published in 1892. In this book he summed up the conventional wisdom of the late 19th century picture of the nature of the scientific enterprise. There is strong evidence that this picture of science found its way into science textbooks and versions of it were perpetuated by generations of textbook authors.

Pearson believed science was essentially an empirical-inductive enterprise that had four characteristics:

1. Science had achieved a superior kind of truth;
2. Science was characterized by inexorable progress;
3. Science was in the possession of the only method of interrogating nature, namely theempirical-inductive method (the scientific method);
4. This method could be simply described and easily taught.

Specifically, Pearson spelled out the steps of the scientific method:

1. Careful and accurate classifications of facts and observation of their correlation and their sequence;
2. The discovery of scientific laws by the aid of the creative imagination;
3. Self-criticism; the final touchstone of equal validity for all normally constituted minds.

. The scientific method, roughly as outlined by Pearson, and later enshrined and perpetuated in science texts is still with the general public and many science educators. In the physics text the author used as a fledgling high school science teacher (Eubank,1963) we find the following steps of the scientific method presented to the student:

1. There is a question or a problem;
2. Collect all the facts about the problem;
3. Propose a theory or possible explanation;
4. Test the theory with an experiment;
5. Repeat the experiment and test to find out “if it will always be true.” If not reject it.
6. If always true, it becomes a law.

It is interesting to note that “scientific law” here follows “scientific theory.”

Most scientists would agree that a complete picture of scientific enterprise that includes what scientists do on a day-to-day basis, cannot be given by the Pearsonian notion of scientific thinking. A contemporary philosopher of science, Rom Harré, sums up the wide range of activities of scientists saying that the scientists’ activities and imagination should span the discovery spectrum “ranging from informal intuitive steps to formal devices” (Harré, 1970)

According to his argument there is a spectrum of scientific involvement that ranges from identifiable mechanical procedures to high-grade activity involving the educated scientific imagination of the research scientist. This is the picture of science that we wish to present and use in this study.

The place of science in general education then was seen as important to the extent the “scientific method” could be taught. Increasing recognition of the practical, social, and social aspects of science in the curriculum was also promoted. However, the applied science tradition was criticized from two sides: The advocates of teaching the theoretical, disciplinary structure of science and the other the advocates of the humanistic cultural aspects of science.

At the time of the “Sputnik Crisis” (1957) at least three competing objectives about the nature, purposes, and emphases of school science can be identified as an activity.

1. A practical, technical, applied emphasis.
2. A liberal, generalist, and humanistic emphasis.
3. A specialist, theoretical, disciplinary emphasis.

The “Sputnik crisis” triggered a flurry of legislation and financial assistance of very high value was given to transform the science curricula in the US. The new large-scale programs later known as PSSC, BSCS, CHEMS, ESCP curricula for secondary science and SCIS for elementary science were developed. These were all heavily funded by the NSF but practical and technological applications of science were neglected. These activities in the US had a delayed, but significant effect on Canadian curriculum development.

Two theoretical structures for effective science teaching and learning were very influential in the early 1960s, namely, “inquiry learning” and “discovery learning”. These approaches were comprehensively described and effectively advocated by Joseph Schwab (*Enquiry into Enquiry*) and Jerome Bruner (*The Act of Discovery*), respectively. Schwab recommended that the teaching of science be based on understanding the “structure of disciplines”. “Discovery learning” aimed to promote thinking and reasoning skills and independent research. These two complementary programs also had a great influence in Canada in the development of science curricula in general. It was later recognized, however, that the problem with the notion of Schwab’s “structure of disciplines” was that *the material objects of knowledge* and the *theoretical objects of knowledge* were not properly separated by teachers. Michael Matthews in his comprehensive study *Science Teaching* (1995) points out that:

> *The structure of disciplines that Bruner and Schwab elevate to the forefront of science learning are structures in the theoretical objects of science: the structure of interrelating definitions and concepts contained in Newton’s Principia, the structure of geometry as*

contained in Euclid's Elements, the structure of evolutionary theory of Darwin's Origin, the structure of Bronsted's acid/base theory or of plate tectonic theory.

The idea is that :

Once these structures are grasped, then distant theorems can be derived from axioms, and predictions can be made about likely intervening species or the acidity of new chlorides, and so on.

Matthews then goes on to say that these are not objects that are contemplated by students who first encounter the study of science.

The initially very popular "discovery learning" described by Brunner was later also recognized to be problematic because:

1. The emphasis was on the 'processes of science' rather than on developing conceptual frames of reference.
2. Most science teachers had never been involved in scientific research.
3. Few scientists are acquainted with the history and philosophy of science.

These curricula in the 1960's were designed specifically to prepare students for university education. Curricular reforms aimed at more than just specifying and arbitrarily sequencing content areas. They were also concerned with attitudes and understanding of science as an activity.

James Rutherford of Harvard Project Physics and director of the AAAS Project 2061 of the early 1990s , stated the progressive view of science teaching in 1964 this way:

When it comes to the teaching of science it is perfectly clear where we, as science teachers, science educators, or scientists, stand: we are unalterably opposed to the rote memorization of the mere facts and minutiae of science. By contrast, we stand foursquare of the scientific method, critical thinking, the scientific attitude, the problem solving approach, the discovery method, and of special interest here, the inquiry method.

The influential American science educator Paul Dehart Hurd lamented the failure of NSF discipline-based reforms of the 1960s to give students a sense of the broader canvas of science by saying in 1987:

The measure of scientific literacy is the measure of cultural awareness. The traditional science curriculum leaves students foreigners in their own culture. A problem in bringing about the essential reform of science teaching is that there are too many scientists that are scientifically illiterate and too few philosophers, sociologists, and historians of science and technology who are interested in pre-college science education

We will discuss the notion of scientific literacy a little later.

The science curricula of the late 1970s and early 1980's began recognizing the importance the emerging research on conceptual development in science education. One discovery approach , promoted by Lawson and Karplus, was popular in the 1970s. They used Piaget's work as their basis, especially his work on cognitive disequilibrium. They asked: "How is cognitive growth generated"? The answer was: "By a process of elf-regulation and adaptation or equilibration"**.** The resolving of discrepancies in a given information to produce a self-consistent representation of this information was considered the goal of science education.

Lawson and Karplus recommended to teach by way of a three-phase model of hypothetico-deductive thinking:

Exploration--→invention--------→discovery, that is,

formal thought = hypothetico-deductive thought + propositional logic.

This mode, based on classic Piagetian cognitive theory, was used throughout the US for about two decades.

In the most cited *Conceptual Change Model* of learning in science, proposed by Strike and Posner in 1982, one mental concept is transformed into another during the process of learning, provided that the self–motivating requirements of intelligibility, plausibility, and fruitfulness are met. The Conceptual Change Model relies primarily on an analogy between the development of science as described by philosophers of science like Kuhn, Lakatos, and Toulmin, and the process of learning science, and it does not describe, in detail, any mental processes that might be involved during conceptual change**.**

What is most relevant to the classroom science teacher is their finding that for individual conceptual change or learning to take place, the following conditions must be met:

1. There must be dissatisfaction with currently held conceptions.
2. The proposed replacement conception must be intelligible.

3. The new conception must be initially plausible.

4. The new conception must be fruitful and diversely connected, that is, it must offer solutions to old problems and to novel ones.

Michael Matthews, in his, says:

The problem for constructivists is how, given their principles, to get children tobelieve, understand, understand and make meaningful scientific ideas that not only transcend their experience, but are often in outright contradiction with their experience.

Matthews goes on to say that :

Some have likened learning science to learning a foreign language: there is an awful lot that just has to be learnt before the totality begins to make sense, and before one can be a critical user of the language.

In conclusion, science educators generally believe that first of all science teachers must *identify, respect* and then *'built upon'* students preconceptions and, secondly, are aware of the four conditions of conceptual change listed above. Finally, it is important for teachers to realize that when they are confronted by a class of 25 students teaching a concept like force, there will not by 25 different conceptualizations of force, but only about 4 or 5. Clusters of students' preconceptions of main concepts have been identified and catalogued by researchers for motion, forces, heat, electricity; in the very comprehensive work by Driver at all.

Teachers' awareness and knowledge of how students learn will not only involve a change of teaching methods, but are more likely to bring about a revolution in classroom culture, including the roles of teachers and students as well as the course goals (Wubbels & Brekelmans, 1997). A constructivist innovative teaching program normally implies modification of teaching tasks/strategies, learning tasks/strategies, and criteria of learning achievements. Thus, the teachers' role shifts from knowledge provider to learning facilitator, and that the student's role shifts from information collector to active practitioner (Hewson & Thorley, 1989; Roth, McRobbie, Lucas & Boutonne, 1997). In addition, the foci of learning achievement may be broadened from mere knowledge accumulation to personal development, including attitudes of learning and adoption of learning strategies (Cross & Angelo, 1992; Donald, 1993; Elby, 1999; Elb).

The science curriculum

Every science curriculum has at least four parts (either explicitly or implicitly stated):

1) A theory about the nature of science;
2) A rationale for the distribution of scientific knowledge, with tacit assumptions about the learning process;
3) An assumption about how scientific knowledge relates to other knowledge, particularly to the humanities; and
4) A concern with the relationship among science technology and society.

The Pan-Canadian document for setting a template for science curricula recognizes that effective teaching toward SL presupposes that science teachers have a good understanding of the nature of science. Recent reviews of the research, however, clearly show that science teachers generally do not possess adequate conceptions of the nature of science. The general recommendations of these findings are that courses in the history and philosophy of science should be included in teacher preparation programs. Can we achieve this promise?

Physics and Scientific Literacy

In Canada, the Pan-Canadian Science Education document, drafted in the middle 1990s by participants from all provinces, provides a framework for local and provincial curriculum developers in science education. The framework is guided by the vision that “all Canadian students, regardless of gender or cultural background, will have an opportunity to develop scientific literacy”. The objectives of this proposal are to develop new conceptual and methodological perspectives in science education and promote scientific literacy (SL) in a more humanistic manner. These perspectives include the development of science stories, historical case studies, contextual settings, scientific narratives, and thematic approaches to help science teachers become more effective in the science classroom. In addition, the project is designed to promote a cross-disciplinary approach to science education and to initiate collaborations and dissemination of knowledge at the international, national, and local levels in a unique and innovative partnership We will look at two physics curricula later, to see how diversely the provinces have responded to the guidance of the PAN - Canadian science document

A quick review of the literature on SL surveys in the United States, Canada and in Europe , however, will show that even the most optimistic estimates of SL levels among the general public do not rise above 10 per cent. Science educators have placed the blame on the predominantly textbook-centered teaching taking place in science classrooms that encourages memorization of “scientific facts” and promotes the often mindless recitation of algorithms. The problem of diminishing interest in science must also be connected to the students’ perceived irrelevance of the content-driven and decontextualized science teaching they encounter in the majority of their classes.

Most science educators recognize that innovative approaches are needed in science education if we want to raise the general level of SL significantly. There is strong evidence that we must strive to connect cognitive activity to context and a story-line: Teaching methods imbedded in contexts and stories are not merely useful, they are essential to conceptual development. Moreover, historical and philosophical contexts assist in the development of students’ understanding of the nature of science and promote critical thinking.

It is now commonplace to say that in order to be effective in the classroom, science teachers (indeed, all teachers) require to have good content knowledge as well as pedagogical content knowledge of their subject. To possess the first is regarded as a necessary but not sufficient condition for successful teaching: teachers must also be well acquainted with good pedagogical practices in general and have a thorough understanding of how students learn the concepts presented to them in particular. The possession of content knowledge presupposes a period of formal training in that subject, usually a minimum of a three year general degree at the university level. To complete the requirements for the future a science teacher it is assumed that he/she has been exposed to and participated in learning about ways of applying sound pedagogical principles and what cognitive theories say about how students learn. This usually takes another two years of studying at a Faculty of Education. To sum up: the new science teacher should be 1. Scientifically literate 2. Understand the nature of science 3. Have a good understanding of cognitive theories and what they say about how students learn

To be scientifically literate on the level of a science teacher presupposes content knowledge of the subject as well as an understanding of the NOS. An understanding of the NOS, in turn, assumes more than a cursory knowledge of the history of science.

Scientific Literacy and the Nature of Science

The following are components of SL which are relevant to this study. While every curriculum project emphasizes the centrality of SL in the teaching of science, there is no one widely accepted set of components for SL. Since an important part of SL is the understanding of NOS, a scientifically literate person is presupposed to have a good understanding of NOS. A Template for Scientific Literacy given below.

A Template for Scientific Literacy:

A scientific literate person is expected to, among other things, to:

1. Understand fundamental concepts, laws, principles, and facts in the basic sciences.
2. Appreciate the variety of scientific methodologies, attitudes and dispositions, and appropriately utilize them.
3. Connect scientific theory to everyday life and recognize chemical, physical and biological processes in the world around them.
4. Recognize the manifold ways that science and its related technology interact with economics, culture and politics of society.
5. Has developed science-related skills that enable him or her to function effectively in careers, leisure activities, and other roles;
6. Has developed interests that will lead to a richer and more satisfying life and one that will include science and life-long learning.
7. Understands significant parts of the history of science, and the ways in which it has shaped, and in turn has been shaped by, cultural, moral and religious forces.

The following is a list of what the possession of an adequate knowledge of the nature (NOS) of science entails. These are selected statements which in my opinion are fundamentally relevant to the discussion in this presentation.

A Template for the Nature of Science

1. There is an "objective" external world, independent of the existence of an observer.
2. Scientists operate on the belief that there are regularities and structures in nature that can be discovered by careful, systematic study.
3. The "objectivity " of science depends on inter-subjective consensus and validation by the community of scientist that work in a particular field of investigation.
4. Scientific theories, are "nets" that contain laws, principles, definitions, and rules of inference that allow us to "catch" the phenomena of the world.
5. These theories guide our thinking and determine what is a "scientific fact".
6. Scientific knowledge, including theories, is tentative and should never be equated with truth. It has only temporary status, albeit often a long one.
7. There can be no sharp distinction made between observation and inference.
8. There is no one specifiable scientific method that can be taught and guarantees success in all scientific investigations.
9. There are different traditions in science about what is investigated and the methodology used, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments.
10. The methods of science are limited to the physical world

Scientific literacy and physics literacy.

Basic scientific literacy (SL) is supposed to be an achievable goal for all our students by the time they complete high school. Those students who complete high school have at least obtained credit in science on the grade 10 level and many have completed at least one course in physics, biology and in chemistry. Of those who successfully complete two courses in physics, chemistry and biology on the grade twelve level the majority will continue their studies in science, engineering, or medical sciences (Rigden, 1991).

We have seen that there is no universally agreed upon definition of SL. Most conventional descriptions, however, involve a certain number of skills, an understanding of science processes and science content, an appreciation of science and technology-all leading to the ability to make wise career choices and informed judgement about scientific and technological research and personal health. However, I think that most science educators would agree that no matter how we define SL it must include a rudimentary knowledge of physics. I would like to argue that an elementary understanding of basic physics must be seen as a <u>necessary</u> but not <u>sufficient</u> part of background knowledge of a scientifically literate person.

First, physics is thought to be the science that has been developed to the highest level of quantitative and theoretical sophistication. Secondly, the fundamental problems we find in all sciences, such as the question of how we construct theories, the nature of explanation and how it is related to prediction, and the question of how science progresses in general, were originally discussed in the context of physics. Finally, physics is considered fundamental, but not reducible to other physical sciences, such as chemistry and to a certain extent biology.

The picture of physics taking a central position in educating toward SL would suggest that if we want to establish a good base for scientific literacy students must encounter the conceptual schemes of physics at a much earlier age than grade 11. In many European countries (England, Germany, Denmark) physics is taught as early as grade 8, and in some countries as early as grade 6. In England all students now must study physics to the GCSE level at age 16 (grade 10). That means that all students will have had instruction in physics for three years. In Canada, on the other hand, students encounter physics in the lower grades but only in small units. Manitoban students, for example, learn some physics directly in <u>short core units</u> usually called <u>Force and Motion, Machines, Heat,</u> as well as in such <u>optional units</u> as <u>Flight, Earthquakes</u> and <u>Earth in Space</u>.

My observations as faculty of education consultant, however, suggests that the physics in these units is mostly taught by way of memorization of facts and the recitation of simple algorithms (definition of density, definition of mechanical advantage and the law of levers, Newton’s second law, Ohm’s law- combined with the solving corresponding simple “type problems”). Knowledge of scientific facts, of course , is important. It is equally important, however, for students to make connection with experiential and intuitive ideas that lead to a good understanding of the evidential and theoretical background in which those facts are imbedded.

As the physicist Anthony P. French, referring to the teaching of physics, has pointed out, “the problem of reaching the average student remains unsolved, and even among the academically talented, scientific literacy is the exception” (French, 1986).

What does research in cognitive science tell us about teaching science?

Even a brief glance at the journal article titles since the late 1980’s will show that the ideas of constructivist learning theories have dominated science education research. There is, of course, a long lag time between the research done in science education and the implementation of the findings of this research into curricula and classroom teaching.

Piaget thought that we make sense of the physical world by content-independent logical structures and operations. Modern constructivists, however, believe that domain-specific knowledge schemes are important and not general reasoning schemes. It is important for science teachers to realize that Piaget was a cognitive scientist and his findings do not constitute a “learning theory”.

Science teachers should know and discuss the basic assumptions of constructivism. These are easily stated:

1. Kowledge is actively constructed by the individual. .
2. Coming to know is an adaptive process that organizes one’s experiential world; it does not discover an independent, pre-existing world outside the mind of the knower.

The degree to which these are taken, determines where on the spectrum one is.

Moreover, research shows that:

1. Learning is experience-based, context-bound and domain-specific.
2. Learning is an adaptive process in which the learners’ conceptual schemes are progressively reconstructed in keeping with a wider range of experiences.
3. Learning is dependent on the preconceptions that learner brings to the educational experience.

4. Learning is highly dependent on the context in which it occurs.

5. Each learner must construct his or her own meaning.

In addition, we must pay attention to the key findings of research in conceptual change in science.that common sense ideas and preconceptions are persistent and often stay with a student into studies at the university level.

CHAPTER 3: THE PHYSICS CLASSROOM

> *Science is built up from facts, as a house is built from stones. But a collection of facts is no more a science than a heap of stones is a home* (Poincare).

> *...we need to redesign our introductory courses to emphasize physics as a process activity rather than just a body of facts and theories. We need to highlight the questions physicists ask of nature, and the methods used to answer those questions* (Robert Hilborn).

> *For more than three decades, physics education researchers have repeatedly shown that traditional introductory physics courses with passive student lectures, recipe labs, and algorithmic problem exams are of limited value in enhancing students' conceptual understanding of the subject* (McDermott and Redish 1999).

The Teaching of Physics

Traditional physics instruction in high school and especially in university involves the presentation of the course material given in a standard lecture. In these lectures, the concepts are are presented as fully-formulated generalizations that are then applied to a few special cases. The students act as passive absorbers of the material and are not required during the lecture to engage intellectually with the ideas being presented. This traditional method is sometimes called the “transmissionist” or “broadcast” mode of teaching. In secondary schools, teachers generally present the topics prescribed by the curriculum in a similar way. After all they learned their physics in a university setting being taught by professors pf physics.

In high schools, most physics teachers seem to assume that students entering their first specialized physics studies in grade 11 (in Canada, students do study basic ideas of physics, such as motion and electricity are inserted in earlier years) have a muddled understanding of motion and forces. Moreover, students are thought to be unprepared for the rigours of learning physics. Students are presented with a mathematical description of phenomena, usually by a lecture-record-retell approach. There is evidence that on the introductory level professors of physics also generally assume a *tabula rasa* condition of the student’s brain, as far as physics concepts are concerned, and teach accordingly. Both high school teachers and university professors seem to take for granted that *well thought-out lessons and clear presentations ensure the acquisition of basic concepts of physics on the part of the student.* That this is not so has been well demonstrated by research into conceptual development in physics, notably by Hestenes (Hestenes, 1992). Hestenes and his group have shown that a clear presentation is a necessary but not sufficient condition for a good understanding of the concepts presented.

Students, of course, have many preconceptions about motion and forces, light, heat, electricity and magnetism that are not consonant with the physicist's conceptions. However, there is strong evidence internationally that even among students of physics at both the high school and college levels many have strong and easily identifiable “misconceptions” about phenomena that are supposed to be elementary and well understood . Van Hise presented a large Japanese study, involving several thousand post-secondary technology schools of students who had successfully completed high school physics. More than 70% of the students could not answer the question posed about forces acting on a car moving with a constant velocity (see Fig.1). Such studies strongly suggest that students who do well on routine physics test go back to their old ‘common sense' views as soon as they discontinue their school physics (Van Hise, 1988, Driver, 1989, Osborne (1981)). This is a very disturbing finding but not surprising when we are reminded that the textbook-centered lecture-record-retell approach is the main method of instruction.

Current research in science (physics) education clearly shows that there is a strong relationship between students’ pre-existing (or alternative) conceptual framework about science (to make sense of the every day world) and the manner in which students respond to new concepts in science in school. Teachers must recognize and respect the learners’ conceptual apparatus before an approach to effect a conceptual change in students can be effectively formulated and presented. Research also shows that students’ views are held because of their utility in every day life, and that conventional formal (expository) instruction has little or no effect in permanently changing these views.

Encouragingly there are, signs that even on the university level professors of physics are becoming aware of this important finding of cognitive research in physics education. However, most physics professors of my acquaintance are not usually knowledgeable about, nor interested in science education research, to understand the conceptual development of students learning physics. It seems that the majority of high school physics teachers as well as university physics professors teach to an audience that is perceived as bimodally distributed, a case of self-fulfilling prophesy: roughly 20% that can do physics and 80% that cannot, no matter how we teach.

There is strong evidence to suggest that these pre-scientific views persist even after students receive good marks on problem solving tests (conventionally regarded as good indicators of the permanent acquisition of knowledge). This is especially true in the teaching of kinematics and dynamics. Indeed, topics in mechanics have become the testing ground for studying the problem of bringing about permanent conceptual change in science (physics) in students.

What can be said about the scientific literacy (SL) of students who do not go on to study physics in grade 11? Few students learn any basic physics (i.e. change their preconceptions to *bona fide* physics conceptions) by way of the piece-meal approach of teaching physics prior to grade 10. Those who do not go on to study physics in grade 11 are then deprived of a fundamental portion of what constitutes basic SL. Many of those who go on to university to study the arts, law and commerce, also remain scientifically illiterate in a fundamental sense. As the physicist Anthony P. French has pointed out, "the problem of reaching the average student remains unsolved, and even among the academically talented, scientific literacy is the exception" (French, 1986).

The teaching of physics and the nature of evidence

To be scientifically literate requires a good understanding of the connection between theory and evidence. Clark Gilmour, a contemporary philosopher of science says that a great deal of the fascination we have for science

> *...derives from the delicacy and the ingenuity with which scientific practitioners attempt to establish the relevancy of some bit of evidence to some bit of theory*.

He goes on to say, "

> *My belief is that many of the features of scientific method, and the grounds for many methodological truisms, derive from features of a general strategy commonly used to establish the relevance of evidence to theory*. (Gilmour, 1980).

The "big" theories of science: Newton's gravitational theory, Darwin's theory of evolution, kinetic molecular theory of gases, Mendeleev's periodic arrangement of the elements, Wegener's continental drift theory, Bohr's theory of the atom, Planck's quantum theory, Einstein's theory of relativity, are not established by the conscious application of a specifiable scientific method. Historians of science and philosophers of science are generally agreed that such theories are not arrived at by way of a specifiable inductive procedure. Rather, they are the product of scientific imagination based on a set of presuppositions (which are not directly testable), previous theories, questions, experiments, deciding what counts as evidence, and lucky guesses.

A high-order theory like Newton's theory of gravitation is not based on systematic analysis of data (although at times data is systematically analyzed). Such a theory should be seen as the sum total of the answers we obtain to our ordered questioning and our selection of evidence, sometimes expressed in a compressed series of mathematical and definitional statements. Moreover, the question-and-answer procedure involves experiments, generates problems that must be solved, often using evidence that is selected on the basis of an incomplete theoretical background. The struggle to achieve a conceptual basis for such a theory involves a continual ordering and re-ordering of questions in response to experimental results. Moreover, what counts as evidence changes with the evolution of the theory.

The theory-evidence-psychology connection

As science educators in a scientific age we are facing the following problem: On the one hand we have available a wide spectrum of textbooks, a proliferation of support scientific literature, modern laboratory equipment, computer-aided interactive programs, and excellent media programs. On the other, we face disinterested, bored, overburdened students who do not find the study of general science in the middle years exciting, or the study of physics or chemistry in high school and in college an intellectual adventure. In junior high schools, too, teachers find that students are frequently "turned off" science. This is not surprising when one considers that they are routinely asked to perform tasks on the basis of a theoretical model that is not connected to an evidential-experiential base that "makes sense". Solving problems based on a memorization of Ohm's law, or memorizing the valences of elements in order to balance chemical equations are good examples of such tasks. At the high school level the problem becomes more acute because textbook-centered teaching is almost exclusively an algorithm-recitation process.

It is commonly known, however, that science teaching is generally textbook-centered (Renner, J. et al). Consequently teaching takes place chiefly on, what we shall call, the logical plane (mathematical-algorithmic-factual), with only occasional tentative excursions to what we shall refer to as the evidential plane (experiential-experimental- intuitive).

How then should we approach the teaching of science in general in view of what we have said? Most successful science teachers argue for frequent contact with the evidential plane in the teaching of physics. However, they assume that this is a straight-forward pedagogical task.

One of the reasons for the failure of science teaching to help students make contact with appropriate evidence may be science teachers' inadequate background knowledge. However, another important reason must be the insufficient attention given to the question of how students learn science concepts.

The general pedagogy of the classroom teacher seldom include, nor do textbooks discuss, the third plane of activity, namely the psychological plane. This plane involves the activities related to how students learn concepts in science. Textbooks, of course, leave the pedagogy, or the question of how students learn science, to the science teacher.

We will make the assertion that in planning successful science teaching we would need to pay attention to all three planes of activity, the *logical*, the *evidential*, and the *psychological*. We have already discussed the theory-evidence connection of science and science learning in the last chapter. We will now add the psychology connection, after a brief description of the three planes of activity.

The Logical Plane

On this plane of activity we encounter the finished products of a science, what we called in the previous chapter the background theory, such as laws, principles, models, theories, and "facts". The basic question on this plane is, "What operation(s) will link the conception to the evidential plane?" because this determines to what extent the activity on the logical plane relates to the evidential plane.

The concepts of density, valence, and specific heat, Newton's second law, F= ma, the principle of conservation of energy, the Bohr model of the atom, the kinetic-molecular theory of gases and the "scientific fact" that the electron is the basic electric charge, are found on this plane.

The following examples, one taken from each of, physics, chemistry, and biology respectively are good illustrations of the textbook's major preoccupation with the logical plane. These are:

a. in physics, the mathematical formulations of Newton's second law of motion (usually first taught in grade 11);

b. in chemistry, the *rules for chemical combination* based on the notion of *valence* of the elements (often first taught as early as grade eight); and

c. in biology, the *circulation of the blood* (also often first taught in grade eight or even before).

Newton's *second law of motion* is usually given as fully developed mathematical formulation often supported only by a teacher generated demonstration. The cognitive linkage between the formal abstraction and the data generated by the demonstration is seldom clearly established. The student is left with a memorized verbalization. Experimental activity, if any, is of the "to verify Newton's second law" type. Students then solve a host of problems from the textbook dealing with motion and forces by applying algorithms.

In the chemistry example a definition of *valence* as "combining power" is given and the algorithm for combining such elements as oxygen and hydrogen are laid out. The explanation of valence is usually wrongly given in terms of the Bohr model of the atom, and students are taught to relate the number of outer shell electrons with valence. The Bohr model then is supposed to be the evidential connection for the rules of combining elements. This topic is usually discussed in grade 11 chemistry in this fashion, but unfortunately it is often taken up in detail as early as in grade eight.

The *circulation of the blood* is usually discussed in grade eight. Students memorize "scientific facts" from diagrams and descriptions in the text. An operational definition, if one is given at all, will refer to pumps and "closed systems". Sometimes teachers may show large scale models of the circulatory system. Students memorize a host of "facts" and study schematics depicting the circulation of the blood. Students must accept, on faith, that the blood circulates throughout the body.

The evidential plane of activity

On this plane of activity we encounter the experimental, intuitive, experiential connections that support what we accumulated on the logical plane. We saw in the previous chapter that the first question we should ask on this plane are, "*What are good reasons for believing that*...?" Here we are looking for evidence that "makes sense" to the student. The second question we should ask is, "What are the diverse connections of this concept?" Here we wish to show that the concept is valid when used in seemingly disparate areas in scientific inquiry.

Thus, when presenting the topic of motion and forces, essentially Newton's second law, we should provide the students with opportunities to consider every-day examples of motion. This should be done in response to such questions as, "What are good reasons for believing that only an unbalanced force acting on an object produces an acceleration?" In response to this question simple experiments should be designed, sometimes initiated by the teacher but more often by the student. The typical textbook experiments of the kind "To verify Newton's second law" should be avoided. We should also delay the presentation of the finished product of the mathematical formulation of Newton's laws, such as F = m x a. Before presenting these "formulas", however, the teacher should consider the question, "What are the diverse connections that led Newton's to his second law?" It turns out that there were three empirical connections: the motion of the pendulum, the results of collisions between hardwood balls attached to two pendula, and the motion of the conical pendulum.

These seemingly disparate phenomena were finally united conceptually by essentially one equation. In other words, the results of these experiments plus the scientific imagination of a Newton produced the equation of motion F= ma. Of course, it is not suggested that we should attempt to recapitulate high-grade scientific thinking when we are working on the evidential plane. However, discussing the evidential basis for the finished mathematical product, such as F= ma, as a splendid science story, can be very motivating as well as illuminating.

The concept of *valence* is taught to students by introducing *ad hoc* rules for writing simple compounds, such as HCl and H_2O. This is done without any evidential basis other than the appeal to the simplified Bohr model of the atom. Students respond to this kind of "evidence" with questions that can always be translated to mean, *Why should I believe this? or provide me with good reasons for believing*... Unfortunately, most science teachers' stock response here would be, "Hydrogen has one electron in the outer shell and therefore has a valence of +1 and Chlorine has seven electrons in the outer shell therefore has a valence of -1 ..." Junior high school students simply do not see the model of the Bohr atom as properly placed on the evidential plane. Students respond with confusion and ultimately with boredom.

Again, as in the case of our example from physics, a historical approach is appropriate. The concept of valence was well established and *diversely connected*, long before Bohr's model of the atom was established in 1913. Originally the "combining power" of elements was connected to the two cornerstones of chemistry, the law of conservation of mass, and the law of definite proportions. Simple experiments, such as the *electrolysis of water*, a demonstration of the chemical combining weights of sulphur and iron, should be devised for students to illustrate these laws. On the basis of such experiments, and on a clear (pre-Bohr atom) understanding of the concepts of element and compound only should the students proceed to write the formulas of simple compounds.

The *circulation of the blood* is studied almost exclusively by memorizing "facts" and schemata from textbooks. The questions one asks on this plane are generally not answered to the satisfaction of the student. For example, little or no attempt is made to recapitulate Harvey's original arguments of why the blood must circulate. Thus the opportunity to involve the student in one of the first "thought experiments" in biology is missed.

A common misunderstanding is that *thought experiments* are highly theoretical and abstract. However, students find the classic thought experiments of physics often more compelling than concrete demonstrations. Harvey's thought experiment to "prove" that the blood must circulate is no exception (Stinner, 1990).

The psychological plane of activity

In this plane of activity we pay attention to the students' pre-scientific knowledge, and to their previous school science. Here we study the responses they have to some key questions we shall pose in testing their readiness to accommodate a concept. Textbooks generally are not directly concerned with the questions we must ask on this plane. It follows that most science teachers engaged in textbook-centered teaching pay little or no attention to how students' preconceptions interact with what is being taught.

The three key questions we will use in making connections between the evidential plane and the logical plane are based on the work of Posner et al (Posner, 1982) and partly on suggestions made regarding the phrasing of subsidiary questions by Hewson et al (Hewson, 1989) (See Fig. 1). The first question sets the necessary precondition for a concept to be considered at all as a candidate for assimilation or accommodation: the student must find a concept intelligible before any meaningful teaching can take place. For example, a student may not find the mathematical formulation of Newton' second law, namely F= ma intelligible, i.e. he/she cannot solve problems involving F= ma consistently without using a mnemonic and without slavishly following an algorithm. Therefore if the first question cannot be answered with certainty we cannot proceed to the second question which sets the stage for establishing plausibility. The student then cannot go beyond meaningless algorithm-recitation on the logical plane, since a connection with the evidential plane is not possible.

The LEP model of conceptual development

We laid out the three planes of activity, the *logical*, the *evidential*, and the *psychological.* To illustrate how these planes are connected we used three commonly taught science topics (two in junior high school and one in senior high school). The three planes of activity were then related by way of the scientific concept.

The modest expectation of this approach is that teachers reflect on the concept they are about to teach, its place, origin, and its relationship to the theoretical background. This reflection should encourage them to collect appropriate evidence that "makes sense" to the student, in answer to the questions, "what are good reasons for believing that..?." and to " what are the diverse connections of the concept?" Finally, it is hoped that teachers would map out the many connections between the activities on the *evidential* and the *logical planes*, filtered through the requirements demanded by the questions on the *psychological* plane.

A large number of publications recently have explored teachers' understanding of the nature of science (Selley, 1989, Martin 1990, Collins 1989, Abell 1989, Davson-Galle 1989, Akeroyd 1989) as well as efforts made to help teachers understand the nature of science (Arons 1989, Rohrlich, 1989, Jordan 1989). Moreover, there is a vigorous attempt on an international level to explore ways to introduce the history and the philosophy of science into science teaching (Brush, 1989; Cushing, 1989; Kenealy, 1989, Matthews, 1989).

A recurrent complaint of these papers is that most teachers perceive science as an empirical-inductive enterprise. This is not surprising, since most textbooks implicitly or explicitly support this picture of science (Selley, 1989). There are, however, difficulties in instituting programs that would involve a philosophical orientation in the preparation of science teachers. One of these difficulties is connected with the question of which of the well-known philosophical views (Popper, Lakatos, Toulmin) one should use (Martin *et al*, 1990).

Perhaps a modest start could be made to take teachers beyond a simplistic understanding of science as an empirical-inductive enterprise. This could be accomplished by having teachers frequently and habitually consider the three planes of activity as outlined here. When using the model, teachers should consult diverse texts and other sources that deal with historical contexts and philosophical issues of science. Science teachers should also collaborate with their colleagues on an on-going basis in finding. The LEP model is discussed in detail in my article

Stinner, A. (1992). Science Textbooks and Science Teaching: From Logic to Evidence. *Science Education*, 76, 1-16.

The transition from High School to University

Finally, we have the problems associated with the transition from high school physics to university physics. In the United States only about 40% of the science-oriented high school graduates complete one of the majors, namely, chemistry, physics or biology (Rigden, 1991). This statistic suggests that something is amiss when students encounter introductory courses in science at the university level. J.S. Rigden and S. Tobias in a widely read article (Rigden and Tobias, 1991) partially blame the rapid pace of the courses, the large class size and the machine-graded examinations for "fostering the erroneous impression that science is authoritarian" as well as rendering students "incredibly passive" in science lectures.

A.P. French believes that one of the reasons for this state of affairs is that the textbook-centered teaching of physics at the university level "has fallen into an appallingly predictable pattern" (French, 1988). He suggested that introductory physics courses not begin with mechanics, where our main task is to confirm the consequences of Newtonian dynamics.This reinforces the belief that "physics is a cut-and dried, finished, essentially dead subject". Recognizing that scientists have obtained their training by way of the textbook, he asks: "But can we honestly say that these courses are providing our students with a real enjoyment of physics? A sense of wonder? He concludes his discussion of the role of textbooks this way: "Therefore, I regard the development of radically different types of textbooks as almost inseparable from the development of more effective physics courses" (French, 1988).

Robert Hilborn agrees with French and states that "Most introductory courses are like coral reefs: They have grown more by accretion than by design", and so students are apt to founder on them. He insists that "we need to redesign our introductory courses to emphasize physics as a process activity rather than just a body of facts and theories. We need to highlight the questions physicists ask of nature, and the methods used to answer those questions".

The teaching of introductory physics at the university level is at the present (2005) still, in the experience of the author, much like the teaching of physics at the senior high school level: it is highly academic, textbook-centered, and locked into a lecture-record-retell sequence. At the university very little time is spent in group discussion, since two hundred or more students are often present in one class, and almost all tests are multiple-choice. To be sure, there are weekly small tutorials supervised by teaching assistants, but these still follow the recall of facts and the learning of algorithms to solve textbook problems in preparation for exams. In addition, most laboratory work in high school**,** if any systematic laboratory work is done at all, is of the verification type: “To show that Ohms’ law describes the relationship between voltage, current and resistance”, and “To verify Newton’s second law of motion”. Laboratory at the university level can be likened to a high-grade assembly-line of prescription-based experiments that have predictable results.

Lesley Dickie, a Canadian physics educator, has looked at the problems that students encounter in the transition from high school to college. He argues that this transition is characterized by an "impedance mismatch". He ascribes the source of the main problems encountered by physics students at the university to the mutual ignorance teachers of physics at these levels have of each other's teaching practices and of their particular milieu. He suggests that the two research findings, namely 1) students prefer classes in which they participate and 2) students can successfully learn by resolving cognitive dissonance by discussing outcomes with peers, point to a constructivist view of learning (Dickie, 1991). These findings imply that university professors should seriously look at the findings of cognitive research. At the high school level, he suggests, that teachers find ways to have students take more responsibility for their actions and results. Finally, he recommends that faculty from physics departments visit high schools and high school teachers visit physics departments. An on-going open and serious-minded discussion between the two levels of physics education is probably a necessary but not sufficient precondition for improving the teaching of physics.

CHAPTER 4: CONTEXTUAL TEACHING AND THE HISTORY OF SCIENCE

> *Knowledge of the history and evolution of our ideas is absolutely vital for wise understanding.*
>
> (Albert Einstein)

> "*...in general, the textbook has been immensely effective, but it is a narrow and rigid education*. (Kuhn, in his SSR, 1962).

> *Science teachers must come to know just how inquiry is in fact conducted in the sciences. Until science teachers have acquired a rather thorough grounding in the history and philosophy of the sciences they teach, this kind of understanding will elude them.*
>
> (James Rutherford; Harvard Project Physics and AAAS Project 2061, 1964).

> … *Mathematics would be much easier to learn if textbooks were written historically*.
>
> (Imre Lakatos, mathematician and philosopher, 1970).

> *The pedagogical task is to produce a simplified history that illuminates the subject matter and promotes student interest in it, yet is not a caricature of the historical events.*
>
> (Michael Matthews, philosopher and educator, 1994)

> *A common complaint of the seers* (physicists working on foundation issues) *is that the standard education in physics ignores the historical and philosophical context in which science develops.*
>
> (Lee Smolin, a "seer", and theoretical physicist, 2005)

Introduction:

In chapter four I discussed science curriculum in general with the emphasis on physics. I argued that the conventional science curriculum is a crowded place. No one planned it that way, it got that way because someone was always coming up with some new bit of scientific information that everyone should know, and few people ever suggested removing anything. While science educators agree that the science curriculum needs to be less crowded, one science educator's weed is another science educator's flower, so nothing ever seems to get removed.

Accordingly, any proposal to add something new to the science curriculum must be accompanied by a convincing argument. In this chapter, I will attempt do just that: I will not only propose something to be added to the science curriculum, but will also suggest a format to deliver it that will make science more meaningful and interesting to students while relieving much of the crowding of the curriculum. My proposal is that the History and Philosophy of Science (HPS), combined with contextual teaching become a central theme in the science curriculum. In effect, I am arguing that HPS and science content knowledge be integrated into a contextual matrix of science stories and large context problems (LCPs). Finally, examples of science stories will be given, drawn from the history of science and suggestions for large context problems that integrate HPS and science content knowledge.

Science for Everyone as a rationale for HPS

Toward the end of the last century, science educators have again been drawn to the newest rallying cry for change in science education: “science for everyone”. While "Science for Everyone" resonates better with 21st Century post-modern democratic-egalitarianism than the elitist sounding "Pursuit of Excellence" of former years, there are other good and sufficient reasons that school science should be for everyone. We were slowly awakening to the realization that science is under siege; that the public mind is becoming disenchanted with science, and beginning to perceive technology as its evil twin.

Science under siege**:**

Today, thanks to science and technology, on the whole, we live longer , healthier and wealthier lives. Why is it then that more and more of us are rejecting science and turning away from technology? On every side and in every walk of intellectual life, from the science elite to the person on the street, we see evidence of a growing disenchantment with science and technology. Indeed, public confidence in science and technology seems almost to be in a condition of free fall. Witness the numbers of well-educated people, often with science backgrounds who quite literally bet their lives against science by eschewing science-based medicine in favour of "alternative medicine"; the post-modernists and their philosophical cousins, the extreme constructivists in science education who deny the relevance and validity of scientific knowledge, the followers of cults and the purchasers of grocery store checkout stand tabloids with their accounts of scientifically implausible events and tales of the supernatural.

I suggest that a major cause of the public's disenchantment with science is a perception of science as arrogant, all-knowing and beyond the comprehension of the average person. In their early encounters with science in elementary and secondary school, which is more often than not, their last, too many students find themselves confronted by what to them appears to be a tangle of complexity comprehensible only to the intellectually nimble and the mathematically gifted. If we are to improve the public mood regarding science, we must introduce students to a "kinder gentler" science that is not only for everyone but is perceived to be for everyone.

What is “Science For Everyone”?

Science for Everyone (SFE) is science that is comprehensible to most students; science that students find meaningful and interesting; science that relates to the everyday lives and experience of students. But what are the properties of a science that is for everyone; how do we give SFE an operational meaning? I contend that if science is to be for everyone science must have the following characteristics.

1. *Comprehensible for most students*: SFE is science that offers essential core of science learnings that is comprehensible to most students, not just the gifted and talented not just the top 30 %, but most students. Science that overloads the memory with too many facts, figures and formulae is boring and incomprehensible to too many students. SFE focuses on the clear essentials of science knowledge and skills and does not make intellectual demands on students that are beyond their capacity to achieve. This comprehensible core must be clearly identified so that both teachers and students know that it is essential. Other material may and should be presented and students encouraged to learn it but it should not be a distraction from the essential "comprehensible core".

   SFE takes into account the level of intellectual development of learners. In the early grades, it focuses on descriptive and inductive intellectual processes. Only in later grades does it draw on hypothetico-deductive processes required for comprehending theoretical conceptions and the deductive processes required for the formulation and testing of hypotheses in later grades.
2. *Meaningful to most students* SFE is science that is meaningful to most students. Evidence abounds that traditional discipline-based science knowledge is not meaningful and therefore not well retained and used outside the classroom. Meaningful science is not bounded by classroom walls: students use it to make sense out of the natural phenomena they experience in their daily lives and to solve their real life problems.
3. *Reflective of the nature of science* SFE has a human face, providing students with real and vicarious experiences in making scientific discoveries and using scientific principles to solve real problems. SFE provides students an opportunity to share in the frustrations and rewards of the intellectual

struggles of those who have made important scientific discoveries It presents science as an eclectic and creative process of search and discovery aimed at understanding how nature works and refutes the notion that science can be described in terms of any sequence of prescribed steps.

SFE reinforces the universality of science as a way of understanding natural phenomena while defining the limits of science in other areas.

4. *Based on sound scientific principles of teaching and learning* Research on teaching and learning has made great strides in recent years. Little of the knowledge about teaching and learning has been incorporated into classroom practice and curriculum development. SFE applies principles derived from studies of cooperative learning, cognitive science, and developmental psychology.

Contextual teaching and the history of science

One approach to teaching SFE could be by way of contextual settings using HPS. Many writers have recently promoted the introduction of HPS into science curricula. We will summarize the recommendations of only three who have, in our opinion, argued particularly convincingly (Matthews, 1989; Winchester, 1989; Jenkins, 1990). They suggest that any introduction of HPS into the science curriculum should:

a.) Be contextual, motivating, informing and relevant to students' concerns and interests.

b.) Ensure that the historical context makes students understand that the present status of scientific knowledge is not inevitable.

c.) Make direct connections with students, who are growing up in a world of electronic global information and complex technologies that bring great benefits but also great risks.

d.) Make students aware of the complex interaction between ethical, religious, ideological and intellectual ideas in negotiating scientific agreement.

e.) Engage students with the values in science, with those in science itself that guide scientists' thinking and those involved in the industrialization and commercialization of science.

What is considered to be reliable scientific knowledge requires agreement among scientists (natural philosophers). To illustrate the dynamics of how that agreement is reached each historical context must make clear the evidential argument that *would have been acceptable* for confirming an assertion at that time. Such arguments usually discuss the relationship between theory, observation, experiment and explanation.

Knowledge of these arguments is expected to contribute toward an improved public scientific literacy and provide a better science education for future scientists. Moreover, well designed historical contexts clarify the evolving nature of the scientific enterprise. It is interesting that Kuhn promoted textbook-centered teaching, noting that "in general it has been immensely effective", nevertheless agreeing that "it is a narrow and rigid education" (Kuhn, 1962, p. 166).

It is puzzling that he did not explicitly recommend a contextual and a historical approach to the teaching of science (physics).

The story-line approach to the teaching of science

Several writers and science education researchers have recently again recommended and have elaborated the notion of using a "story line" approach to the teaching of science. Arons (1989) believes the best way to attract students' attention as well as organize a science course is by way of a "story line". He outlines in some detail the historical settings of important discoveries and events. Arons is referring to what are essentially good science stories that have intrinsic interest and show connections not to be found in textbooks. These stories seem to be excellent small versions of Conant's case histories "that can be infused into introductory courses, without seriously affecting the amount of physics being covered" (Arons, 1989).

Michael Ruse has designed a large-scale case study based on the controversy between creationism and the theory of evolution. He uses this study to set a large context with *one unifying central idea that attracts the imagination of students*. He says: "rather than simply going straight at students with such worthy (but boring) standard topics as criteria of confirmation, conditions for adequate explanation, and the like- at least, rather than going at students abstract isolation- one does better to plunge into actual areas of science, from which the pertinent philosophical messages can be extracted" (Ruse, 1989). In other words, he set a large context problem (LCP) that *generates the major ideas and problems of the philosophy of science naturally* (Stinner, 1989; and Stinner and Williams, 1993).

Jutta Luhl, a German science teacher, has developed a "story-line" approach to teach atomic theory in Middle Schools. Rather than "teach the Bohr model of the atom at a very mechanical level", she has developed a mini-course that traces the development of the idea of *atom* from the Ionians to Dalton (Luhl, 1990). Like Ruse, Luhl set a large context in which one central idea that attracts the imagination of the student the important connections that lead up to the Bohr atom are explored. These include an understanding of the historical evolution of the idea of the *atom,* including basic principles, such as the conservation of mass and energy and the law of definite proportions. This approach may be more time-consuming then the conventional textbook approach. However, the understanding of the student as well as the quality of interaction between the student and the teacher is lifted from an ordinary to a high-grade level.

Wandersee has been using Egan's *Story Form* in developing what he calls *Historical Vignettes* to enhance the teaching of science to young students. He uses "carefully chosen examples from the history of science...tailored to the interests of the science students..,"(Wandersee, 1990).

In seems that all of these writers to a lesser or greater extent recommend a "story-line" organization of a science topic that resembles our original LCP approach (Stinner and Williams, 1993, Stinner, 1994). In summary, the central features are based on the following guideleines:

1. Map out a context with one unifying central idea.
2. Provide the student with experiences that can be related to his/her everyday world.
3. Invent a "story line" that will dramatize and highlight the main idea.
4. Ensure that the major ideas, concepts and problems of the topic are generated by the context naturally.
5. Ensure that the problem situations come out of the context and are intrinsically interesting.
6. Show that concepts are *diversely connected*, within the setting of the story as well as with present-day science and technology.

Ideally, the science story should be designed by the instructor, in cooperation with students, where he/she assumes the role of the *research-leader* and the student becomes part of an on-going research program. I will continue this discussion in chapter 5 where we will look closer at the design of the LCP.

Claims for the inclusion of HPS in the science curriculum:

The following is a summary or composite of claims made by many science educators (Matthews, Winchester) for the inclusion of the history of science in the science (physics) curriculum, as I present them for discussion to my science teacher candidates at the University of Manitoba. I consider this list complete, but not exhaustive, while conceding that many claims are general and overlapping. The central guiding idea I use is the one given in the quote at the head of the chapter by the Michael Matthews:

> *The pedagogical task is to produce a simplified history that illuminates the subject matter and promotes student interest in it, yet is not a caricature of the historical events.*

1. History promotes a better understanding of scientific concepts and methods.
2. History is a storehouse for educational ideas, experiments, and interesting case studies.
3. History connects the development of individual thinking with the development of scientific ideas.
4. History presents science as a dynamic and often revolutionary process. This process can be seen as an adventure in ideas that adds to the totality of the human experience.
5. Important episodes in the history of science and culture should be familiar to all students.
6. History of science is necessary to understand the nature of science.
7. Recent research has shown a parallel between the discovery process and the learning process.
8. History counteracts the scientism and dogmatism that are often found in the media and even in texts and classrooms.
9. History teaches that scientific theories are tentative, but sometimes very robust and shows how and why it so difficult it is to overthrow critically established ideas in science.
10. History allows us to compare the difficulties we encounter in today's scientific theories with those of earlier times. This comparison may help us understand the limits of our theories better, clearing a path toward further development in research.

11. History allows connections to be made within topics and disciplines of science as well as with other disciplines.
12 History often provides simple examples that show how science, technology and society are interdependent. Even the origin of certain scientific mythologies can be demonstrated through historical studies.
13. History humanizes the subject matter of science.

Researchers have found clear parallels between students' intuitive conceptions in science (mechanics, electricity, heat) and historical pre-scientific conceptions. Although this finding suggests that it may be possible to have the learning process recapitulate the historical process, closer examination of the complex thinking involved in scientific discovery shows that setting such a goal is probably unreasonable. A plausible case, however, can be made for a limited recapitulation of the historical process in domains, such as pre-Newtonian mechanics, that are experientially familiar to the students.

For pre-Newtonian physics the conceptual development depends on commonsense perceptions based on personal kinesthetic memory. On the other hand, post-Newtonian concepts are related to internalist notions such as thought experiments that may be difficult to connect to ordinary experience. Moreover, it may be that physics teachers themselves have generally limited acquaintance with the ideas of Mach and Einstein. Teachers therefore tend to believe that the 'discovery argumentation' required for presenting these ideas would be too difficult for beginning physics students. It may, however, be possible to also achieve partial recapitulation of post-Newtonian ideas of force and motion with high school physics students.

The "Units of Historical Presentation" in science teaching

I will briefly outline what our HPS group calls "the units of historical presentation". This is not an exhaustive list but includes most approaches used in placing science in context and in the presentation of history. In designing these units our pre-service teachers use the guidelines given below.

Vignettes. The smallest unit of presentation is the historical vignette, developed and discussed in great detail by Wandersee (1992). He argues that introducing a well-crafted and well-chosen vignette into the classroom connects the concepts and ideas under study with the interests of the student. Vignettes should also "serve as motivation and encouragement for students to read more about science and scientists" (Wandersee, 1992, p. 21).

Case Studies. Case studies are historical contexts with one unifying idea, designed according to the guidelines for writing a large context problem (LCP), shown in Fig. 1. Students form groups of three and make a commitment for planning a case study. Each group is asked to present the case study in three parts, one part prepared by each student:

1. *Historical context:* Student one presents the scientific ideas of the historical period and show how they are connected to the topic.
2. *The experiment(s) and the main ideas*: Main ideas and/or empirical support for what is central to the case study is presented by student two, assisted by his/her colleagues. If possible, these demonstrations should also involve the students in the audience.
3. *Implications for scientific literacy and the teaching of science:* Student three responds to the following questions:

   "Where do the concepts fit in the science curriculum?'

   "How would one present these concepts, ideas,experiments in the classroom?

   "What are the diverse connections of the concepts under discussion?'

Confrontations. We are inclined to think of modern science as having resolved most issues. Quite the contrary is true; science in the 20th century is fraught with confrontations, some completely or partly resolved, and others still raging. Sometimes there are many competing theories seeking to lay the foundations of a new discipline, as in the case of the eighteenth-century science of electricity and Lavoisier's new chemistry and the alchemists, but mostly scientific confrontation is the squaring off between two rival theories.

Thematic narratives. This approach identifies general themes that transcend the boundaries of individual scientific disciplines and may have interdisciplinary and humanistic connections. For example, the thematic couple of atomism and continuum "played an important role in shaping the conceptual structure of early twentieth-century biology and science" (Jordan, 1989). Other themes could be conservation, time, regularity and evolution. These themes transcend individual disciplines and often link major activities in the various disciplines and touch on humanistic activities. It is often convenient to connect several small case studies to produce a continuous narrative with an underlying theme.

Dialogues. Galileo used the dialogue format in his books in order to dramatise his science. To make his "new science" more accessible to the general reader he wrote the text in Italian rather than in the conventional Latin. Galileo's approach has been "rediscovered" by several science educators (Lockhead & Dufresne, 1989; Raman, 1980): "The method I discovered recently was to present the relevant information and ideas in the form of a dialogue in which the original scientists are made to speak of their ideas and theories" (Raman, 1980, p. 580). The following dialogues have been developed and presented in class by students: Copernicus and the Aristotelians; A creationist confronts an evolutionist; Priestley and Lavoisier discuss the relative merits of phlogiston and oxygen theories in explaining combustion and 'calcination'.

Dramatization. The role of the scientist in society has been a subject for playwrights for hundreds of years, many modern plays have been written about science and scientists in modern society (Brecht: *The Life of Galileo*; Golding: *The Physicists*; Kipphard: *In the Matter of J. Oppenheimer*. Recently the play *Copenhagen* that is essentially a dialogue between Heisenberg and Bohr in 1941 has been playing to capacity audiences in Europe and North America. Jonathan Duveen and Joan Solomon (1994) have written and used such plays as *The Great Evolution Trial* to encourage students to role-play in the classroom.

In our science history classes we have developed dramas (as amateur playwrights, of course) for the purpose of presenting them in a science classroom. They have been quite successful in the University setting: *The Trial of Galileo*; *The public debate between science and the Church of England*: Darwin (actually, his "bulldog" Huxley) confronts Bishop Wilberforce; *The Age-of-the-Earth debate* (A debate set in 1872, with Kelvin, Huxley, Lyell, and Helmholtz representing the disciplines of physics, biology, geology, and cosmology).

Remarks about contextual teaching: From Early Years to Universit

I believe that a science curriculum should be humanistic, context-based, and well connected to a sound theoretical structure It should contain a sequence of theoretical and empirical experiences involving contextual teaching, science stories, thematic teaching, and popular science literature teaching. For early years (K-grade 4) one would like to see a program of simple science stories that deal with the child's conceptions of the world. We want to recognize, respect and build on children's early conceptions, using motivating contexts that involve an exciting story-line and employ a number of first hand experiences. These activities should be guided by a sound conceptual development model. The model should assume that teachers will neither challenge children's “common sense” science with scientist's science, nor attempt to impose scientific understanding on children. Rather, teachers help children to build domain-specific knowledge and effective scientific reasoning by means of scaffolded instruction that is carefully attuned to children’s prior experience and thinking. Ways to guide conceptual development of children between the ages of six and ten involve experiences that enable restructuring of conceptual models through first-hand investigations that make public what is observed and inferred (cf. Gallas, 1994, talking, writing, dancing, drawing, and singing understanding of the world). These exploration, practice, and application activities are one part of a sequence of carefully designed lessons that build on examples, analogy, themes, theories, or models inaccessible to young children through everyday experiences or common sense reasoning.

It is hoped that the science stories will be connected to a program of activities like those suggested for an early introduction to physics by Osborne and Monk (Osborne, 1984; Monk, 1994). These activities would involve air tables to study motion qualitatively, watching and discussing objects falling in air and in a vacuum, learning that words have different meanings in different contexts, discussing images and passages from stories and films and discussing, after experience makes obvious, the need for clear definitions in science.

For middle years these early stories and contextual activities could be followed by science stories based on history, and by contexts based on students' experiences and on contemporary issues that students are interested in. The science of the Greeks, because it is essentially high-grade thinking based on unaided observation, seems especially well suited for teaching science in the middle years.

In the senior years case studies can be introduced that discuss one main idea and/or experiment as well as those that discuss science *thematically*. Many science teachers, of course, already use, at least implicitly, such themes as the corpuscular nature of matter, the notion of conservation, and the wave-particle duality of matter. The criterion of selectivity here should be based on how well known the outcome of the story is. Physics teachers interested in using history of science know that telling the story of Galileo and the inclined plane often fails to make an impact if the description of the motion has already been learned from a textbook.

Contextual settings, including science stories, of course, can also deal with the relationship between science and technology and society. Clearly, STS themes that are now very popular can easily be accommodated by the contextual teaching discussed here. Indeed, students at the University of Manitoba and the University of Winnipeg have developed LCPs based on such themes as *Nuclear Energy, The Flood of the Century, Food Processing and Irradiation*, and *Genetic Engineering*. STS issues will emphasize the added dimension of the relationship between science, technology and society. However, we must try to make the context for STS teaching interesting and appropriate for the student, roughly as suggested by the guidelines for writing LCPs and science stories.

For the college and first year university science classroom we need large scale discussions, extensive well crafted contexts that do not shy away from detail and mathematical complexity.

The Proper Insertion of the UHPs

The following is a brief discussion of the proper insertion of the UHPs, or the various modes of presentation in the science classroom for all levels. Monk and Osborne (1997) present a sound and well-argued pedagogical model that allows the insertion of the HPS alongside each major idea or concept discussed in the science classroom. They point out that we cannot rely on textbooks to incorporate significant HPS, and that the prevalent model for the incorporation of HPS in science education has been the occasional addition to supplement and “humanize” the text book-centred science taught. On the other hand, a complete historical presentation, along the lines of Harvard Project Physics (HPP) must be considered impractical. HPP was a heroic effort to teach physics entirely by using sequences of historical contexts connected by large themes that unfortunately ended as a “glorious failure”. The text for this splendid course is still available and there are “islands of excellence” in the US were high school physics is taught using this text by exemplary and intrepid physics teachers.

Contextual teaching in middle years science

Many of the main ideas and concepts in biology, chemistry, and physics of the 18th and the first half of the 19th century can be discussed in middle years education and many of the key experiments replicated. The story of Lavoisier and the chemical revolution and Dalton atomic theory is appropriate for middle years science. In biology, teachers should develop simplified approaches to show how Pasteur's experiments refuted spontaneous generation and how Semmelweiss' observation led to the germ theory of disease. Most of the classic experiments of Faraday on electricity and magnetism, as well as those of Joule in establishing the principle of the conservation of energy, are easily replicated and the relevant concepts are amenable to elementary analysis. We probably should do better here than what conventional textbooks allow us to achieve.

Count Rumford and the Caloric Theory of Heat

I have chosen a vignette that discusses a famous confrontation in science that most textbook report in one or two sentences. This mode of presentation can be considered as a “mini-confrontation”, suitable for the late middle years science class.

The Historical Context

Count Rumford (Benjamin Thompson) was one of the most colourful and imaginative scientists of modern times. He was an amazing character, a combination of an eighteenth century James Bond and Indiana Jones. Most textbooks make a fleeting historical reference to him in connection with his experiments that “refuted the caloric theory of heat”. Even a cursory review of the history, however, will reveal that the real story is more complicated and much more interesting. Rumford was an excellent physicist and one of the most imaginative experimenters of the eighteenth century, investigating a host of seemingly diverse physical phenomena.

Benjamin Thompson was born in poverty in 1753 in Woburn, in colonial Massachusetts. He was later known as Count Rumford, General of the Army in Bavaria, famous scientist, versatile inventor, public benefactor, and a clever spy. He was very interested in scientific ideas, mechanical devices, and experiments involving heat, light, and gunnery. He made original contributions to each of these areas (see Brown, 1962, 1968-1970, 1976 for fuller accounts of the life and achievements of Count Rumford). Among his many legacies are the famous “Englische Garten” in Munich and the Royal Institute of London. Today, the former is the favourite park of the inhabitants of Munich and the latter still serves as a well attended forum for public education of science and technology in London.

At the age of fifty-eight, Count Rumford left London and spent his last years in Paris. He married Lavoisier's widow, but the relationship turned out to be stormy one, much to the delight of Parisian society. In Paris, he continued his scientific investigations that ranged from the study of radiation of heat to the invention of a dynamometer to test the efficiency of a horse-drawn carriage.

Rumford died suddenly in Paris in 1814, at the age of sixty-one. His scientific investigations included seminal work in radiation of heat from different kinds of surfaces, diffusion of liquids and gases, measurement of the mechanical equivalent of heat (anticipating Joules' work by some thirty years), development of the photometer to measure light intensity, studies of the transference of heat through a vacuum (the first to clearly differentiate between radiation, convection, and conduction in heat transfer), experiments to test the caloric theory of heat, and the determination of the density of water at various temperatures.

Main Ideas and Experiments

In order to explain such phenomena as thermal expansion, experimental results of calorimetry, latent heat of water, and the conduction of heat in metals, the *caloric theory* was developed. The caloric theory has left us with a legacy to be found in such conventional expressions as “the flow of heat”, “heat capacity”, and the less often used “latent heat”, “heat of vaporization”, and “specific heat”. The theory was very successful and was championed by the greatest scientists of the day, including Lavoisier, Laplace, Priestly, and others. Indeed, even Rumford's brilliant experiments were not sufficient to overthrow the theory until decades after his death.

The theory seemed to be a remarkable triumph of rational intelligence (Wilson, 1960, p. 61). It could account for the difference between solids, liquids, and gases, for the conduction of heat in solids, and for thermal expansion. The theory was only partially successful in explaining why the specific heat of solids must increase with temperature and why conduction of heat should increase with the density of a solid. However, the caloric theory encountered great difficulties when trying to explain the “latent heat” of substances, why compression of a substance should squeeze out caloric, and why, when pressure is applied the solids, gases, and liquids, their temperature rose.

Rumford was in charge of the work in the Bavarian military arsenal, supervising the boring and the finishing of canons in the 1780's. He believed that the heat involved in this action was much more than could be accounted for by adding up the total amount of heat in the casting, the cutting tool, and the chips. He designed an elegant experiment to test this hypothesis that *the heat generated by friction appeared to be inexhaustible*, even when the bodies rubbed together where perfectly insulated. Rumford then asked two fundamental questions: "Whence then came this heat?" and "What is heat actually?" Referring back a hundred years before him, he believed that Boyle and Hooke must have been right when they suggested that "heat is nothing but a vibratory motion taking place among the particles of the body" (Wilson, 1960, p. 164).

Implications for the Science Classroom

Many of the experiments that Rumford performed can be replicated by students in late middle years and the first senior years. However, before doing so, teachers could present the caloric theory along the lines previously suggested and discuss it as an explanatory theory for many everyday phenomena. Following that, teachers could set up experiments inspired by Rumford.

After completing the experiment and discussing the results as well as Rumford's explanation for his heat experiments, students could be given an abridged version of the letter the famous John Dalton wrote to Rumford. Dalton vigorously disagreed with Rumford's explanation. Dalton, who believed in the caloric theory, argued that once a body was in temperature equilibrium with its surroundings, it was in a state of complete rest. That is, all the atoms and molecules would be in a state of complete rest. Rumford, however, countered that there was a connection between heat and motion even at equilibrium temperature. To show that this was so, he performed the following experiment that students could try to replicate.

Rumford took two liquids, a salt solution and pure (distilled) water, and put them in a glass container in such a way that the salt was at the bottom of the glass and the water on the top. He put the water in first and then introduced the salt solution below the water by pouring it through a funnel to the bottom of the glass. Then he dropped a single drop of oil of cloves into the glass. The drop sank in the water but floated in the salt solution, coming to rest halfway down the liquid column. The whole experiment was carried out in his cellar, where the temperature was constant. He found that eventually the drop of oil of cloves rose slowly to the surface. His explanation was that the internal motions of particles of the liquid continued even at temperature equilibrium, which contradicted the caloric theory of heat.

Who was Benjamin Thompson? Was he an adventurer, a statesman, a military genius, a great inventor, a social benefactor, perhaps a great scientist? Clearly, Rumford does did not fit the popular stereotype of the reclusive, introverted scientist. By examining their personal lives and while tracking their paths to the discovery of fundamental and far-reaching scientific principles in the context of scientific knowledge and beliefs of their time, students will come to understand that science is something other than the revealed truth as it often seems to be portrayed in textbooks. Of course, this same approach can be used with more contemporary scientists such as James Watson, Francis Crick, Linus Pauling and Steven Hawking.

Senior Years Science

In senior years students begin to move from a descriptive mode of science to a more explanatory mode through the use of models, laws, and theories. We have previously stated that science education continues to focus on a textbook-centered presentation of the finished form of science which views science as an established body of knowledge where the models, laws, and theories of science require minimal justification. In spite of recent curricular efforts (Pan-Canadian science frameworks) to promote a more eclectic view of science and an understanding of the nature of science, few contexts exist where such a view may be practised in the classroom. I am arguing that, in many cases, the historical development of conceptual models (HDCM) will provide such a context to meet many of the goals and outcomes of the Pan-Canadian view of the nature of science.

A model is a representation of an idea, object, event, process, or system (Gilbert & Boulter, 1995) that can be expressed in many different ways (as diagrams, physical models, language). We infer and build imaginative models that connect our experiences and observations with scientific theory. Models, therefore, hold a position between our observed reality and scientific theory. Gilbert and Osborne (1980) also suggest that models enable concentrating study on special features of a phenomenon and that models stimulate investigations by supporting visualisation of the phenomenon.

Gobert and Buckley (2000) recently outlined the basic assumptions and underlying principles of research programs in model-based teaching and learning. They accept the position that people construct and reason with mental models, and that the evaluation of a model may lead the learner to reject or revise the model. Buckley describes model-based learning as a dynamic, recursive process that involves the formation, testing, and reinforcement, revision, or rejection of mental models. In her study, Buckley uses various models of the heart as a means of developing an understanding of the circulatory system and as an avenue for the learner to generate and consider further inquiries. In lieu of a factual accounting of the relationship between the circulatory and digestive systems, students use a multimedia approach based on an anatomical context which provides open access, when needed, to relevant information.

As we have argued in chapter 1, learning in science is well motivated by contextual teaching, and that another way to achieve this is through the context of history. The context of history provides the student with a sense that scientific theories are developed in a historical setting, and that confrontations and competing theories in science play an important role in the development of new ideas. Understanding how scientific concepts were acquired in the first place enables the learner to view the products and processes of science in a more authentic view of the nature of science.

Recent curricular efforts, like Project 2061 and the Pan-Canadian science frameworks, suggest that the nature of science should play a prominent role in today's science curriculum. However, little or no context is provided for teachers to implement goals such as the "development of scientific theories and technologies over time" (p. 26) in the science classroom. Lederman (1998) argues for a more explicit treatment of the nature of science. I suggest that the HDCM can provide a context for addressing these nature of science outcomes explicitly in a pedagogically sound and motivating manner.

The inclusion of the historical development of conceptual models naturally promotes a better understanding of the nature of science. In general, models are viewed as more tentative than theories or laws. Additionally, the contributions by many individuals over time, portrays science as a more humanistic endeavour, marked by intellectual struggles, and personal and cultural influences. In this sense, we move from the naive view that textbook models are an exact replica of nature to the view that models are products of human creativity and imagination. Justi and Gilbert (2000) also suggest that the development of historical models outlines a more authentic understanding of the philosophy of science. They propose a Lakatosian view of science using questions such as "how does the model overcome explanatory shortcomings of its predecessor or competitor", to focus attention on degenerating or progressive research programmes.

In another effort to advance a philosophically valid curriculum, Hodson (1988) argues that as children begin to acquire more experience they need to develop their personal theories into more complex structures and pass through several developmental stages. These stages include a tentative introduction of several models, a search for evidence, selection of the best model through discussion and criticism, and further elaboration of the model into a more sophisticated theory. In science instruction, students should be able to introduce their own experiences, make their own ideas explicit through writing and discussion, and explore, challenge, and devise tests for alternative viewpoints.

Final form science, today’s textbook approach, does not permit the opportunity for the student to develop tentative models. HDCM allows students to consider their preconceptions in the light of some of the early conceptions of great scientists. These early ideas form an introduction of a tentative model which can be confronted by unsolved puzzles and discrepant events as the model is modified or replaced by more a plausible model. Further, it promotes a better understanding of the nature of science by encouraging students to challenge early models of science and, ultimately, their own conceptions. The following example outlines an HDCM strategy that can be used to introduce electricity in a secondary science classroom.

Science Education as well as Science students at the University of Manitoba have designed over one hundred large context problems and about as many case studies. The case studies are collected at the end of the semester and students sometimes use them in their teaching. They can be placed in about 20 groups, from *Archimedes’ discovery of the law of flotation* and *Torricelli’s experiment to determine the weight of the atmosphere* to *Mendel’s experiments in plant-hybridization*, *John Dalton and his atomic theory*, and *Faraday’s electromagnetic experiments*. We have also developed dialogues (*Copernicus and the Aristotelians*), confrontations, (*Dalton’s atomic theory* and *Priestley’s affinity theory in chemistry*). Finally, we have written science dramas such as *The Age-of-the-Earth debate*. This dramatization of a prolonged scientific confrontation among physics, geology, and biology was developed by on of us (Stinner) and performed at the IHPST conference in Como and later for the general public at the Deutsches Museum, Munich in November, 2000. The performance was also shown on Bavarian Television in December 2000 and again in January 2001.

Unfortunately, a systematic way of incorporating these case studies (various units of presentation) into formal school teaching has not yet been developed. As a consequence, evidence of their effectiveness is only anecdotal

I believe that what is further needed is an international effort guided by historians, scientists, educators, and teachers, that will respond to Heilbron’s challenge of writing materials and finding pedagogically sound ways of incorporating HPS in science education. It is time that the ideas of James Conant’s case studies be updated and revised to serve the needs of 21st century students and societies. The expertise and the motivation are available. We do, however, need guidance and funding.

CHAPTER 5:

THE DESIGN AND IMPLEMENTATION OF THE LARGE CONTEXT PROBLEM

....It takes a lot of work to move from a traditional teaching style to a contextual learning style. To move from traditional to contextual learning, teachers need new equipment, new strategies, new expectations, new skills and new roles. Teachers have to learn how to ask different questions. With contextual learning a teacher's role is to guide, discuss, create an environment, question, listen and clarify. A student's role is to explore, investigate, validate, discuss, represent and conduct. And both teachers and students have to learn together. John Souders Jr, (1999) taken from his website: http://www.nae.edu/nae/naetech.nsf/weblinks/kgrg-582sq2?opendocument

Introduction

I will begin this chapter with a comment made by John Souders of the Center for Occupational Research and Development (CORD) about contextually based learning and the difficulties encountered by educators and teachers.

Reading his comments, it is clear that we are faced with a paradigm shift when changing from traditional textbook-centered teaching to a context-centered teaching required by the LCP approach. The basic assumptions about how students learn science have radically changed. As Kuhn pointed out, in a paradigm change, those who come to face assumptions of the new approach late in life, can sometimes be *converted*, while those who grow up with them are *persuaded* at an early age and become comfortable with the new ideas and concepts. I suspect that physics teachers who have been teaching using a textbook-centered approach for a long time (especially if well done and deemed successful, based on conventional evaluation) will be reluctant to use an approach like the contextual approach outlined here. Again, quoting from Sounders:

There is wide acceptance of contextual learning but there are many obstacles to overcome before it is widely accepted in classrooms across the country. It is integrated into the latest secondary textbooks, supported by leading educational writers, endorsed and included in the standards from the National Council of Teachers of Mathematics and the American Association of Community Colleges. But is the motivation there within teachers to learn how to teach contextually?

A brief history of the LCP approach

The superiority of a contextual approach over the conventional textbook-centered teaching in physics became clear to me after designing and successfully using my first large context setting for a senior physics class in a Canadian (Toronto) high school. What I later came to call the "large context problem" (LCP) approach was originally developed as a response to the discovery that *learning could be well motivated by a context with one unifying central idea capable of capturing the imagination of the students.*

In the first article that I published about a contextual approach to the teaching of physics (*The Crucible,* Journal of the Ontario Science Teachers' Association of Ontario, March 1973), the introductory paragraph reads:

> *In the constant effort to infuse enthusiasm and relevance into the teaching of physics, we rearrange, supplement, and delete from the traditional textbook -oriented approach. Physics by its very nature must be taught hierarchically: the basic grammar of kinematics necessarily precedes a discussion of Newton's laws. The problem then is to modify the methods traditionally in order to escape the sterility of the structured abstractions of physics as a discipline*.

The text continues:

> *Is it not possible, for example, to apply simple kinematics to a situation that is little more exciting than finding the acceleration of a car? Or, in mechanics, solving a problem involving the unbalanced force that causes a certain acceleration of a given mass? Or, in a study of light and wave motion, finding the position of equal intensity between two light sources?*

The introduction then concludes this way:

> *Assuming that the teacher will proceed in the prescribed hierarchical progression "space-time- motion" to "wave motion and light" to electricity and modern physics" I would like to describe briefly a few related investigations that I have used for enrichment in Grade 13 physics classes and found effective*. (See disc for the complete article)

The article then continues in describing 1) "Launching a Rocket into the Stratosphere", 2) "Physics on the Moon", and 3) "Sun Power in the Pyrenees". The updated versions of the last two are contained in the LCPs presentation.

Finally, the objectives for designing LCPs have essentially not changed from those written out in the article of 1973:

In summary, the objectives for these investigations are, to :

·

1. achieve maximum utilization of acquired knowledge of physics,
2. break the monotony of compartmentalized “type questions”
3. make physics as a discipline more relevant to the students’ experiences.
4. involve, motivate, and create enthusiasm, and
5 give students an opportunity to work in groups, and present solution to the class.

My first attempt to design a LCP was based on a detailed report by *Time* magazine (*Time*, May 18, 1970) on the construction of the still largest (2007) solar furnace in the world, operating in the Pyrenees, Southern France. What struck me was that the article described the solar furnace in sufficient detail to allow the setting of an investigation that involved a great deal of the students’ knowledge of physics. The original version of this detailed report can be seen in the DVD (LCP 3) accompanying this book,

Guided by the context, my students generated questions and problems that were inherently more interesting than similar problems presented in textbooks. I collected these questions and found that it was possible to involve the main concepts, laws, and principles of the traditional study of optics, light, and radiation. In addition, it became clear that students welcomed the opportunity to go beyond the textbook material to discussing black body radiation and thermonuclear production of energy in the sun. Moreover, it was central to the context to determine the energy output of the sun that is based on the value of the solar constant, the radiation energy intercepted per second per unit area, just outside the atmosphere. Students seemed to enjoy working on and discussing problems such as the radiation concentration on a small focal area (about 0.1 m^2), the time it would take to melt through a 3-cm thick steel plate, and the temperature reached at the focal point on an ideal “black body**”.**

This was the modest beginning, or the prototype of what later led to the idea of the large context problem (LCP) approach to the teaching of physics.

Encouraged by the success of this, I developed the following LCPs: *Physics on the Moon*, and *Launching a Rocket into the Stratosphere* (1973). These were followed by *Physics and the Bionic Man* (1980), *A Solar House for Northern Latitudes* (1978), *The Physics of Star Trek* (1981), *Physics and the Dambusters* (1989), *The Story of Force* (1994), *The Ubiquitous Pendulum*: (2003), *Calculating of the Age of the Earth and the Sun:* (2002*)*, *Sudden Impact: The Physics of Asteroid Collisions* (2003*)*. and

Voyage to Mars, the physics of travelling to the red planet (2005) (Most of these have been published and are all available in the LCPs presentation)

Early experiences using of LCPs

While teaching the conventional senior high school physics program in the late 1970s and early 1980's , I incorporated LCPs into my daily teaching with increasing confidence. I began with the frequent insertion of appropriate LCPs for each major topic, namely, kinematics, Newtonian dynamics, planetary motion, electricity and magnetism, wave motion, and radiation. For the topics of kinematics and dynamics students could work with *Physics and theBionic Man*, *Physics on the Moon*, *Physics and the Dambusters,* or *The Story of Force*; for planetary motion with *A Rotating Space Station,* or *The Physics of Star Trek*; for electricity and magnetism with *A Fossil Fuel Power Plant*, *Electricity in the Home,* or *The Experiments of Faraday*; for radiation and thermal physics with *Solar Power in the Pyrenees* and *A Solar House for Northern Latitudes.*

I would ask my students to form small groups of three to four and together choose one from my growing portfolio of LCPs that attracted their common interest. Each LCP was designed so that most of the physics for a particular topic would have to be used for the successful completion of the problems suggested by the context. What is so attractive about this kind of setting is that the questions and problems are generated naturally by the context and will *include* problems that are given out of context (in a contrived way) in a textbook. Moreover, students' responses to the LCP approach suggest that ideally LCPs should be designed cooperatively by students working with the instructor. Working as a team also gives the instructor the status of researcher and the student the experience of participating in an on-going research program. Indeed, many of the questions and problems generated do not have obvious answers for the student or even the instructor. The ability to answer questions and solve problems that do not have textbook answers, but *using elementary physics and mathematics only*, is very rewarding for both students and teacher.

Based on my early experiences using LCPs in the physics classroom, I came to the conclusion that contextual approach to the teaching of physics may be more time-consuming than the conventional textbook approach. The extra time spent arises primarily from the teacher's presenting of the context and the students' formulation of questions and problems.

However, what was important was that the students' understanding, as well as the quality of interaction between the student and the teacher, is lifted from an ordinary to a high-grade level.

Later I presented general guidelines for the planning and the development of large context problems, as can be seen below. In my science education classes at the University of Manitoba I have had students design LCPs for science in general and physics in particular with notable success and enthusiastic cooperation. Many of these LCPs were later used in physics classes when these students began teaching physics. The majority of these students who are now teaching physics in the classrooms of Manitoba are persuaded that a context-centered teaching is the most effective way to teach science and physics.

Can we place LCPs in a central position in existing curricula and teaching practices? Originally the LCP was placed peripherally to the textbook and the curriculum. I used LCPs mainly to reinforce core material to the extent that time was available. The high school physics curricula in Canada (in most provinces) at that time generally consisted of a core content surrounded by "options". The core and the sequencing of topics was conventional. The options were contexts such as "Solar Energy" and "Motion: Earth and Sky" that I realized could be developed into good LCPs. Unfortunately, the options were generally considered "interesting supplementary material", and if used at all, discussed only in a hurried manner. Both teachers and students are primarily interested in "covering the material" in preparation for the next level of physics or science course. The mandate to "cover" the material in the curriculum is still with us.

Physics teachers, of course, have been enculturated into the discipline of physics by way of the textbook. Therefore, they tend to believe that the best way to learn physics is by presenting the decontextualized mathematical generalizations of elementary physics illustrated by a host of textbook problems such as "Calculate the distance fallen by a heavy object in 2.5 seconds", and by experiments such as "Verify Newton's second law, using a dynamic cart and pulleys".

Thus, concepts and topics such as density, motion and forces, the physics of heat, light, and sound are not to be introduced by way of textbook-centered teaching, where memorization and algorithm- recitation are the main vehicle for teaching concepts. Rather, the learning of science (physics) should be "seen to involve more than the individual making sense of his or her personal experiences but also being initiated into the 'ways of seeing' which have been established and found to be fruitful by the scientific community" (Driver, 1989).

Most physics teachers would likely not be comfortable using an LCP like *Physics of the Bionic Man*, or *Physics on the Moon, The Physics of Star Trek* as a context from which to begin teaching elementary kinematics or Newtonian dynamics. They would rightly point out that the general problem encountered in contextually-based science teaching is that *we set contexts that attract students and motivate them to acquire content knowledge, but students cannot deal with the questions and the problems that the context generates unless they already have some content knowledge*.

However, I believe that it is still superior to a conventional textbook and lecture-centered approach to begin with a context that attracts students' interest and is connected to their experiences. The teacher involves the students in generating questions and problems, and in proposing simple experiments and then developing the equations of motion in response to those questions and problems. Developing the appropriate physics would, then, relate to students' interests and the direct contextual application of the "formulas" might enhance their understanding of how theory is related to practice. A pedagogically sounder approach, however, would be to place the students into small groups and have them choose among many LCPs to begin the study of physics. The instructor could then first develop the physics that responds to the core questions and problems of all LCPs investigated by the students and later refine the development to cover all the queries. Each group would then present their questions, problems, and experiments and discuss how and to what extent they have formulated solutions to these and then show the results of their experiments. At the end, a comparison and pooling of these results could be produced by the whole class.

Experienced teachers know that for students to consider the learning of science interesting and relevant, a number of conditions for context-based learning must be satisfied. First, the context should be so planned that the questions and the problems that are generated capture the students' interest and that they seem "real" and make sense to the students. Secondly, teachers should keep in mind that for a contextual setting to get off the ground at all, students must be able to, at the beginning, answer a few basic questions and solve a number of problems with little effort.

Thirdly, students should be prepared to face, with a measure of enthusiasm and confidence, questions that they cannot answer easily. Finally, group discussions, guidance and plenty of well sequenced concrete activities must be seen as essential in motivating young students to learn new relevant content, preferably expressed in the students' own words.

The LCP and the history of science

In preparation for suggesting a template for the LCP presentation in general I will refer to my experiences in my history of science classes at the University of Manitoba, which are entirely contextually oriented. The classes are student- centered, there are no conventional lectures, nor do we have a prescribed textbook. The classes are three hours long. There are many differences between these students and senior high school student, but there are also many similarities. (See my website)

I have developed two history of science courses, and we have offered these every year since 1989 to education students since 1989 and to students from the Department of Physics and Astronomy as a physics credit, since 1995 . The education students are in the after-degree program; they usually have a B.Sc. and sometimes a B.A. The science students are mostly 3. or 4. year students (the course can be taken by second year students) working toward a science degree. It is gratifying that many of these students upon completion of their degree decide to enter the Faculty of Education. Students' background in science (physics) ranges from not having studied any physics after high school to those who have decided to become science teachers after receiving an M.Sc. (The detailed outline of the courses can be downloaded be found on my website).

Every major topic, is presented in the following format:

1. <u>The description of the historical context</u> .

   Students are asked to form groups of two and prepare *historical contexts*; for example, they may present "The physics of Aristotle", or "Archimedes and his discovery of the law of flotation". Three or four of these contexts are presented to the class and serve to *initiate and encourage class discussion.* Students summarize their presentations on 1 page only (both sides) and hand these out to each member of the class, before the beginning of the class. Each presentation is guided by

a. The historical context, i.e. the scientific ideas of the historical period and how they are connected to the topic.

b. The main experiments / demonstrations involved,

c. Implications for scientific literacy and teaching.

These contexts serve to initiate and encourage class discussion. In addition, the presenters conclude with questions and problems that students answer and discuss, to be revisited in the next period and supervised by the presenters.

Each class then begins with a discussion of the questions and problems set in the contexts, conducted by the presenters.

2. Brief commentaries

Sometimes the instructor gives a brief commentary on an important aspect (for about 5 minutes) to introduce, illustrate or illuminate an idea or concept, when the student presentation is made.

3. Case Study presentation

The course makes provision for historical case study presentation as the last part of the course. For a case study presentation students are asked to form groups of three (with at least one education student in the group) and make a commitment for planning a case study. This commitment will be made no later than the middle of the lecture-discussion phase. Each group is asked to present the case study in three parts, one part prepared by each student.

The presentation is between 45 minutes and one hour.

Contextual learning is a teaching strategy that is used widely within Tech Prep programs. It provides an alternate means of meeting student needs. The contextual learning approach is based on an understanding of learning as a complex process that cannot be addressed adequately through drill-oriented stimulus-response methodologies. The assumption underlying contextual learning recognizes that the mind seeks meaning through relationships which make sense and fit with past experiences. This approach encourages educators to design learning environments that incorporate as many different forms of experience as possible -- social, cultural, physical, and psychological -- in working toward the desired learning outcome. When knowledge is placed within the context of its use, students learn more quickly and develop a deeper understanding of how new concepts apply to the real world.

The LCPs that have been developed

(If published, the journal and the date of publication is indicated. Many of these have been updated and placed in the DVD, accompanying this booklet).

Intuitive Physics

Physics and the Bionic Man (*Physics Teacher*, 1980)

The Physics of Star Trek *(New Scientist*, 1981)

A Solar House for Northern Latitudes (*Physics Teacher*, 1978)

Solar Power in the Pyrenees (*Crucible,* 1973)

The Launching of the Space Shuttle

Physics and the Dambusters (*Physics Education*, 1989)

Physics on the Moon (*Crucible*, 1973)

The Rotating Space Station

The Thought Experiments of Galileo, Newton and Einstein (*Physics in Canada*, 2006)

The Physics of Driving (Unpublished, but available).

<u>LCPs that are partially developed:</u>

Dirac's Large Number Hypothesis

Extraterrestrial Life in the universe.

The Physics of...: Baseball, Tennis, the Violin, the Piano,

the Boomerang, Diving, Judo etc.

<u>Historical contexts developed:</u>

The Story of Force: From Aristotle to Einstein (*Physics Education*, 1994).

Galileo's Inclined Plane Experimen.

Faraday's Experiments in Electricity and Magnetism.

The Three Laws of Physics Discovered by the Greeks.

The Great Research Experiments of Newtonian Physics

Newton's Mechanical Experiments, Atwood's Machine. .

Cavendish's Experiment, Foucault's Pendulum.

Michelson and Morley Experiment, Eotvos' Experiment.

The Story of Light: *From the Greeks to Newton and Huygens, to Roemer, Young, Foucault, Michelson, and Maxwell, Einstein.* (A workshop presentation)

The Story of Energy: The *Greeks, Da Vinci, Stevin, Galileo, Newton, Leibnitz, Bernoulli, J., Euler, Lagrange, Carnot, Helmholtz, Kelvin, Einstein.*

(A workshop presentation).

The design of the LCP

The design of each LCP described is guided by the following format**:**

1. The main idea of the context

In Chapter 1 we discussed the necessity of providing contexts that capture the interest and imagination of the student. The large context approach for the teaching of physics was originally developed as a response to the discovery that

> *…learning could be well motivated by a context with one unifying central idea capable of capturing the imagination of the students.*

Every LCP presented is based on a main idea that can be stated and precisely outlined. This is done for each LCP developed..

2. The presentation of the context

Each LCP should contain contextual activities and then specifying the recommended teaching and learning strategies.

*Contextual Activities***:**

Sequencing of carefully designed activities, including the use of

a. bridging analogies,

b. group discussions,

c. evidential arguments, connecting theory and experiment

d. computer-based programs,

e. designing of multi-media programs.

f. discrepant events, etc…

Guiding Questions: (See Table on page)

1. The questions that are generated by the context and how do they fall into one of the following categories**:**

a. Pedagogical questions .	Question for students
b. Research questions	Research for students
c. Foundation questions	Questions asked by original investigator

2. The problems that the context generates and how do they fall into the following categories:

a. Pedagogical problems	Problems for students
b. Research problems	Research problems for students
c. Foundation problems	Problems solved by original investigator

3. What are the experiments and demonstrations, that the context generates and how do they fall into the following categories:

a Pedagogical experiments	Experiments for students
b. Research experiments	Research experiments for students
d. Foundation experiments	Experiments performed by original investigator
e. Thought experiments	TEs posed by original investigator, and TEs for the student.

Note: Foundation questions, problems and experiments, as placed in the *Levels of Investigation in Scientific Inquiry*, generally occur only in historical contexts. Clear distinction between research questions, problems and experiments for scientists and students will be made. The internet links are indicated by IL X where X is a number. Every IL has a brief description and all ILs are listed at the end of the text.

Students' responses to the LCP approach suggest that the questions, problems and experiments should be discussed cooperatively by students working with the instructor. Working as a team also gives the instructor the status of researcher and the student the experience of participating in an on- going research program. Indeed, many of the questions and problems generated do not have obvious answers for the student or even the instructor. The ability to answer questions and solve problems that do not have textbook answers, but *using elementary physics and mathematics only*, is very rewarding for both students and teacher.

3. CURRICULUM CONNECTIONS

Specific connections to the general physics curriculum for high school physics will be made and explicitly stated. We wish to show that a. all requirements (outcomes) of the curriculum are satisfied, and b. that the questions, problems and experiments generated by the context not only match those given in the textbooks but are richer and go beyond those students would have solved using a textbook-centered approach.

We need to find a scheme and structure to achieve this connection so that teachers and students are able to find all connections at a glance.

Guidelines for writing LCPs

The following are suggested guidelines for designing a LCP:

1. Map out a context with one unifying central idea that is deemed important in science *and* is likely to capture the imagination of the student.
2. Provide the student with experiences that can be related to his/her everyday world as well as being simply and effectively explained by scientists' science but at a level that "makes sense" to the student.
3. Invent a "story line" (may be historical) that will dramatize and highlight the main idea. Identify an important event associated with a person or persons and find binary opposites, or conflicting characters or events (Egan, 1986) that may be appropriate to include in the story.
4. Ensure that the major ideas, concepts and problems of the topic are generated by the context naturally; that it will include those the student would learn piece-meal in a conventional textbook approach.
5. Secure the path from romance to precision to generalization (Whitehead, 1929). This is best accomplished by showing the student that

    a. problem situations come out of the context and are intrinsically interesting;
    b. that concepts are diversely connected, within the setting of the story as

well as with present-day science and technology;

c. there is room for individual extension and generalization of ideas, problems and conclusions.

6. Map out and design the context, ideally in cooperation with students, where you as the teacher assume the role of the research-leader and the student becomes part of an on-going research program.

7. Resolve the conflict that was generated by the context and find connections between the ideas and concepts discussed with the corresponding ones of today.

The instructor could then first develop the physics that responds to the core questions and problems of all the parts of the LCPs investigated by the students and later refine the development to cover all the queries. Each group would then present their solutions and answers to questions, problems, and experiments and discuss how and to what extent they have formulated solutions to these and then show the results of their experiments. At the end, a comparison and pooling of these results could be produced by the whole class. See appendix for Fig. 1.

The implementation of LCPs in the conventional topics of physics.

(Many of these have been incorporated in the DVD part of this work).

I. MECHANICS
(KINEMATICS AND DYNAMICS)

1. Intuitive physics.
2. The experiments of Newton using pendula.
3. Bionics and the "six-million –dollar man".
4. Physics on the moon.
5. The rotating space station (RSS).
6. The kinematics and dynamics of a rocket launch.
7. Physics of driving.
8. The physics of the amusement park.
9. Physics of sports.
10. Physics and the dambusters.

11. The story of force: from Aristotle to Einstein.

12. Galileo’s inclined plane experiment.

13. The ubiquitous pendulum.

14. The thought Experiments of Galileo, Newton and Einstein.

15. The physics of Star Trek.

16. Newton's Mechanical Experiments,
17. Atwood's Machine.
18. Cavendish's Experiment,
19. Foucault's Pendulum,
20. Michelson and Morley Experiment,
21. Eotvos' Experiment.

II OPTICS, WAVE MOTION, RADIATION

1. Solar Power in the Pyrenees.

2. A Solar House for Northern Latitudes.

3. The story of light, from Galileo to Einstein.

4. The ubiquitous Doppler effect.

III. ELECTRICITY AND MAGNETISM

1. Renewable energy sources: Wind Turbines

2. Electricity in the home

3. A hydro-electric plant

4. The electric car

5. History of electrostatic machines, from the Leyden jar to the Van de Graaf generator.

6. Faraday's Experiments in Electricity and Magnetism.

IV. MODERN PHYSICS

The high school physics teacher should have elementary content knowledge of the topics mentioned below. This list is taken from my syllabus for teacher candidates that are preparing for a teaching position on high school physics.

For each topic prepare to discuss:

I. The historical Context
II. The experiment/main ideas involved
III. Implications for the teaching of high school physics

(Get your information from text books, journals, books, Internet...).

Roentgen and the Discovery of X-Rays (1895)

Becquerel and the Discovery of Radioactivity (1896)

J.J. Thomson and the discovery of the electron (1897)

Planck and Black Body Radiation (1900)

Einstein and the Photoelectric Effect

The Special Theory of Relativity (1905)

Rutherford's Gold Foil Experiment (1909)

Bohr's Theory of the Hydrogen Atom (1913)

Millikan's Oil Drop Experiment

Compton’s Experiment (1923)

De Broglie's Particle-Wave Model (1923)

Schroedinger's Wave Mechanics (1926)

Heisenberg's Uncertainty Principle (1926)

Dirac's Theory of Antiparticles (1930)

The *Standard Model* and the Four Fundamental Forces (1960-)

Big Bang Theory of Cosmology (1948-)

Black Holes (1790-1915-1937-1967-1974)

References to technology (the physics involved) should include:

Nuclear Power Plants (1955-)

The LASER (1960)

Geiger Counters (1913)

Smoke Detectors (1960?)

Transistors and Semiconductors (1949)

Light-Emitting Diodes (1970)

The Electron-Gun (TV) (1897-)

Superconductivity (1913-present)

Microwaves (1949)

Holography (1951-1960)

CAT, EMR. PET and MRI applications in medicine (1970-)

HISTORICAL CONTEXTS BEING DEVELOPED:

The Three Laws of Physics Discovered by the Greeks

The Story of Light:
From the Greeks to Newton and Huygens, to Roemer, Young, Foucault, Michelson, and Maxwell, Einstein.

The Story of Energy:

Greeks, Da Vinci, Stevin, Galileo, Newton, Leibnitz,

Bernoulli, J., Euler, Lagrange, Carnot, Helmholz, Kelvin, Einstein.

Chapter six discusses the use of thought experiments in the physics class room, and is based on the article published in *Physics in Canada* (Nov/Dec, 2006), entitled:

Thought Experiments, Einstein, and Physics Education

The Contexts of Inquiry in Scientific Thinking

The final stage in the evolution of the LCP approach I developed was in response to the need to connect the activities of studying physics to a structure (or scaffolding) that illuminates the status of theory and evidence, clarifies the relationship between experiment and explanation, and makes connection to the history of science. Additionally, the contextual base must also be connected to constructivist learning theories (Stinner, 1992; also see Figure 1 in the Appendix). Most textbooks do not consciously imbed their content in a theoretical structure of physics, such as outlined here, nor is the history of physics connected beyond interesting anecdotal vignettes. Indeed, textbooks generally implicitly or explicitly promote an ahistorical and empiricist-inductivist picture of science, namely, the belief that laws and discoveries are a guaranteed consequence of systematic observation based on a specifiable scientific method that guarantees success and can be learned.

I will call this theoretical structure or scaffolding *the contexts of inquiry* and have described these in detail (Stinner, 1989, 1994). I argue that in order to come to grips with the nature of scientific thinking in physics we must establish a theoretical scaffolding for the student we may call *contexts of inquiry* in scientific thinking. These are (a) *The Context of Questions*, (b) *The Context of Method*, (c) *The Context of Problems*, (d) *The Context of Experiments*, and (e) *The Context of History*. The *contexts of inquiry* for Newtonian physics are available in my articles. Also see Figure 1, where a table "Levels of Investigation for Scientific Inquiry" is shown.

The placing of the LCP is central in connecting to the *contexts of inquiry* in a given area of physics, such as Newtonian physics. See the relevant articles below. Most of my articles can be downloaded from my website: www.ArthurStinner.com

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