THE NOTION OF EVIDENCE IN SCIENCE TEXTBOOKS

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BY

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Abstract

This thesis attempts to provide science teachers with a way to help students understand the scientific enterprise. It is argued that an understanding of the notion of evidence and how it relates to theory formation can make a significant contribution to the development of students' scientific understanding.

To acquire scientific knowledge individuals must examine and evaluate evidence that supports a scientific theory. Examining theory development in turn, shows how science changes over time. The development of two scientific theories are discussed using the notion of evidence. Four science textbooks are examined and evaluated on their ability to present adequately both scientists' and pedagogical evidence to students.

It is important for science teachers to understand the notion of evidence as it applies to theory development. The conclusion of this argument is that science textbooks must show theory development using the notion of evidence, and that this understanding can make a significant contribution to the students' understanding of how the scientific enterprise works.

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Chapter 1

Introduction

Most educators would agree that one of the important goals in science education is to help students understand the nature of the scientific enterprise. To help accomplish this goal, however, teachers rely almost exclusively on science textbooks. The Science Council of Canada found that ninety percent of students use science textbooks and eighty percent of teachers plan lessons using textbooks as a guide (Science Council of Canada, 1984; Orpwood & Souque, 1984). How textbooks present the scientific enterprise is important because it plays a key role in forming the image of science that is held by students (Finley, 1983; O'Brien, 1990; Abell, 1989). However, science textbooks have been criticized for presenting a poor image of how science actually works. In fact, students often acquire an almost production-line image of science from textbooks (Martin, Kass, Brouwer, 1990; Elliott and Nagel, 1987). In addition, 'textbook science' tends to be overly standardized and simplified in order to present a smooth road to scientific knowledge (Science Council of Canada, 1984, Nadeau and Desautels, 1984). Duschl criticized science textbooks for presenting what he calls the "final form of science" in which textbooks "present changes in scientific knowledge with little regard for the dynamics which prompted them" (Duschl, 1990, p.69). He argues that science textbooks focus mainly on the prevailing scientific knowledge claims, that is, on the products of science.

They only address ***what*** is known by science which he refers to as **scientific knowledge.** As a result students will have no alternative except to memorize and accept, or dismiss the knowledge claims presented by the textbook (Duschl, 1990).

Reporting on high school Biology textbooks, Gallagher states that authors report what science knows and present scientific knowledge as the 'revealed truth'. Virtually no information is given by these authors about how science has come to know what it knows and no information is given "about the manner in which scientists formulated their knowledge" (Gallagher, 1991, p.123). Unfortunately, as a result, students perceive science as logical, always correct, a dialogue of successes, or a representation of the final form of the present view of the world .

However, science is continually changing as new theories are developed, as new evidence becomes available and as scientists acquire more knowledge about the world. Scientists formulate theories to explain and predict *how* and *why* the world works the way it does. Duschl (1990) refers to ***why*** scientists believe what they do and ***how*** they arrive at their knowledge claims collectively as **knowledge of science.** He argues that theories are the key to understanding how the knowledge of science changes over time. Scientific theories play a major role in determining research questions, methodologies, and standards for evaluating investigative results. Moreover, he claims that if students are given the opportunity to examine and to evaluate scientific theories, then they will understand why and how scientific knowledge grows.

In the construction of a view of the world, scientific inquiry is determined by theoretical commitments of scientists. Theories, in turn, can be evaluated by examining evidence relating to the theory. The greater the support for a theory, the greater the probability that the theory is "true".

More specifically, students who evaluate theories and evidence as part of scientific inquiry will have to seriously examine a scientist's theoretical commitment, explanations, and evidential arguments. No matter what makes theoretical backgrounds acceptable or unacceptable to scientists, they use criteria based on standards of measurement, selection of important research questions, designing of experiments, and evaluating experimental results. Students, therefore, must learn to ask: "what questions were asked by scientists?", "what evidence and evidential arguments did the scientist have to support a theory?", "what experiments were accomplished?" and "what knowledge claims resulted?"

Duschl goes on to argue that textbooks could play an important role in answering these questions for students. This role requires textbooks to report why scientists believe what they do and how these beliefs lead to the construction of theories. Textbooks should report sufficient scientific evidence and give evidential arguments to provide support for theories. Duschl argues that if science textbook authors "neglect the fundamental concepts of scientific change" and do not examine "the reasons scientists use to change scientific methods, beliefs, processes" then they "are running the risk of developing students who do not acknowledge scientists' views as rational and as the end product of a process in which changes are both natural and expected" (Duschl, 1990, p.11).

Kilbourn (1980) calls this lack of knowledge of science in textbooks "epistemological flatness". He states that if science is taken out of its historical, political and social context and presented without the critical background material necessary, then students will have difficulty in understanding the meanings and transitions of science. If only the facts are taught and no background is incorporated, then the students must fill in the gaps themselves. For example, science textbooks often state the geocentric model of the universe followed by a claim that this model stood for 1500 years before the heliocentric model was proposed. However, generally textbooks do not report how and why these theories were proposed in the first place, why the geocentric model withstood the test of time for so long and why the heliocentric model eventually replaced the geocentric model. Moreover, textbooks generally do not report why new developments in science are not included in the textbook. Students, then, do not have the opportunity to examine and evaluate any evidence which supports these theories or even to be aware of changes that occurred in astronomy during those years. Duschl (1990) goes on to say that if students cannot understand or at least appreciate what counts as scientific evidence, then there is little hope that they will understand the conclusion drawn from the evidence. As a result, students will not understand the interaction between evidence and theories and how and why scientific theories are formulated.

I will argue that students must understand the notion of evidence if they are going to understand how the scientific enterprise works. Textbook authors, therefore, must report how and why scientists formulate their theories, why these theories change over time and how knowledge claims are determined. Moreover, textbooks must report what counts as evidence, how this evidence supports a theory and how knowledge claims are determined. In order to accomplish these things, I will argue that textbook authors will have to clearly state scientists' presuppositions, and show how these presuppositions and background knowledge guide scientists to produce their theories, give meaning to their observations, and help them develop evidential arguments.

I will then go on to examine and evaluate science textbooks. Science textbooks used in the middle years will be analyzed to determine how they report evidence and whether or not these reports adequately present the growth of knowledge of science according to the picture of science I have presented. Questions that I will address to determine how the textbooks present the notion of evidence include:

1.) Do science textbooks report to students how science knowledge changes over time or do they present the "final form of science"?

2.) How do textbooks use other evidence such as pedagogical evidence, to help students understand the scientific enterprise?

3.) Are science textbooks successful in portraying the proper image of science to students?

To explore these questions in detail I will examine two theories in four science textbooks to determine if they report how science changes over time. I wish to know whether textbooks report why and how scientists construct theories. In addition, I also want to know how they search for and evaluate evidence, what scientific reasoning they use in their arguments, and finally, what knowledge claims are created from their inquiry.

Secondly, I want to evaluate the pedagogical evidence presented to students by two science textbooks. I am concerned with how science textbooks use pedagogical evidence to give credibility to their reports of science.

The notion of pedagogical evidence is stressed by Deanna Kuhn and Susan Carey. They argue that if students learn to evaluate and examine scientific theories using evidence, then they should be encouraged to examine and evaluate their own theories about how the world works. Moreover, how scientists develop their theories is not dissimilar from the way students develop their personal views of the world (Kuhn, Amsel, O'Loughlin, 1988; and Carey, Evans, Honda, Jay, Unger, 1989).

Stinner (1992) also argues that children's level of cognitive development must be addressed in science education if students are to have any chance of understanding science.

In the next chapter I will discuss the literature pertaining to the notion of evidence as presented in science textbooks. Chapter three outlines the notion of evidence with specific reference to the individual's and to the scientist's notion of evidence. Specific examples will be used to illustrate the similarities and the differences between the individuals' and scientists' notion of evidence.

Chapter four examines two examples of theory development. The first example will show how Wegener formulated the continental drift theory and how his theory eventually evolved into the plate tectonics theory. The second example will illustrate the development of the gene theory from Mendel's heredity theory to the development of the D.N.A. model.

Chapter five includes criteria to analyze science textbooks. These criteria are listed under the topics of background knowledge, knowledge claims, and evidential arguments that textbooks present to students. Each criterion will be discussed and questions posed so that reports of evidence, in science textbooks, can be examined and evaluated. The next three sections in chapter five describe the science textbooks that are to be analyzed and discussed. These discussions will include how textbooks treat evidence when they use the evolution of the continental drift theory to the plate tectonics theory and the evolution of the gene theory as examples.

Finally, the last chapter raises some implications for science teaching and textbook writing. I will argue that science textbooks that report the notion of evidence can help teachers in their planning and implementation of lessons. Moreover, I will argue that science teachers must first understand the role that evidence plays in the scientific enterprise. Teachers can then help students to examine and evaluate scientific evidence. I will then suggest resources that teachers can use to aid them and students in understanding how and why the scientific enterprise works.

Chapter 2
Literature review

I will assume at the outset that an understanding of the notion of evidence is essential for students to acquire knowledge of science. There are numerous research reports on how science textbooks are used in science education but most are concerned with the readability of the text (Wood & Wood, 1988; Meyer, Crummey, & Greer, 1988; Vachon & Haney, 1983; Strube, 1989), how they treat the nature of science (Souque, 1987; Lerner & Bennetta, 1988) and what importance they place on misconceptions (Mahadeva, 1989; Denny, 1983; Renner, Abraham, Grzybowski, & Marek, 1990). There are only a few reports which deal with how science textbooks report the notion of evidence.

For my argument the most important study on the notion of evidence in science textbooks is by Duschl (1990). In his book Restructuring Science Education, he states that textbooks must present how and why science changes so that students will acquire knowledge of science. He argues that textbooks must report how and why scientists construct theories and how these theories change over time. In addition, he emphasizes that science textbooks must present evidence which supports a theory. Students can then examine and evaluate that support.

The second study on evidence and science textbooks that is important for my argument is presented by Stinner (1992). He argues that science textbooks generally emphasize the logical plane which he identifies with the mathematical-algorithmicfactual aspects of science concepts. He suggests that science textbooks make connections with the evidential plane which he identifies with the "experimental, intuitive and experiential connections that support what we accumulated on the logical plane". He maintains that the main question that science textbooks must address on this plane is "What are good reasons for believing that..." (Stinner, 1992, p. 7).

Thomas Kuhn also provides insight into evidence and science textbooks in his influential book, The Structure of Scientific Revolutions (1970). He claims that exemplars, that is, "the concrete problem-solutions that students encounter from the start of their scientific education, whether in laboratories, on examinations or at the ends of chapters in science texts" is "learning consequential things about nature" (Kuhn, 1970, p.187). Kuhn claims that science textbooks are successful in producing students who are competent problem solvers in "normal" science. According to Kuhn then, exemplars serve as evidence for students.

The book Conditions of Knowledge (1965), by Scheffler is also important to my argument. Although he does not discuss the notion of evidence found in science textbooks specifically, his philosophical ideas about evidence are important for my argument. Scheffler claims that for individuals to "know" something, they must satisfy three conditions for knowledge. The condition that I am interested in as it applies to my thesis is what Scheffler called the **evidence condition**. This condition constitutes the ability of an individual to justify or back up a belief condition, usually made in the form of a knowledge claim, with support. The evidence condition then serves to "distinguish genuine knowing from mere belief, by reference to appropriate evaluation of the belief by the believer"(Scheffler, 1965, p.56). The strength of knowing consists in the knowers "having adequate evidence for the belief in question" (Scheffler, 1965, p.56).

The final researcher I am considering, who wrote on evidence and textbooks, is Kilbourn (1970). He states that problems existed when he considered using evidence alone to examine and evaluate science textbooks. Kilbourn claims that the term **evidence** is generally restricted to direct observation of an event. Due to many problems associated with the term evidence, Kilbourn uses a more general term which he calls **support.** He outlines four categories for conceptualizing the kinds of support for knowledge claims in science textbooks. These categories include the following: reports of direct observations, reference to evidence, reference to theories, to natural laws and to hypotheses, and finally an appeal to authority.

All the above researchers, however, suggest the need for science textbooks to consciously incorporate the notion of evidence in their discussions of science. Students will then have an opportunity to understand how the scientific enterprise works. Before I examine the development of scientific theories in science textbooks, however, I must first explain what the notion of evidence is for scientists as well as non-scientists. This examination will provide the background for investigating how science textbooks report the notion of evidence and whether these reports can form the basis for a good understanding of the scientific enterprise.

Chapter 3
The Notion of Evidence

I will argue that what counts as evidence must first depend on an individual's **presuppositions** about the world and his/her **background knowledge**. Collingwood (1962) claims that presuppositions determine what questions will be asked. Moreover, these presuppositions will guide the individual in his or her inquiry. For example, Kepler presupposed that the universe could be described by Pythagorian solids, Euclidean geometry and the astronomy attributed to Apollonius (Koestler,1963; & Wilson,1980). One of Kepler's first questions was to ask how the orbits of the planets could be mathematically explained.

An individual will then use these presuppositions and background knowledge to make sense of observations. I will also argue that one will be able to interpret his or her meaningful observations as evidence. An individual can then use evidence to construct evidential arguments and to make knowledge claims. One can then build a partially developed theory.

3.1 Individual's Notion of Evidence

To make sense of even the simplest of observations, individuals need presuppositions and have to have a certain background knowledge in order to give meaning to observations. Once the connections have been made between individuals' presuppositions, background knowledge, and observations, they can then construct initial theories to explain and predict how things work. I will refer to such observations as **evidence**. Initial theories can range from the naive theories children have to sophisticated theories that scientists propose. Individuals develop **evidential arguments** based on collected evidence, as well as their ingenuity, to support and develop theories. To collect evidence one can ask questions, solve problems, and do experiments. In the process of constructing evidential arguments, individuals will then be able to make **knowledge claims** about the world.

Theories, of course, are repeatedly revised and refined as more supporting evidence becomes available and the individual's background knowledge grows. In fact, new evidence can be used as a basis for developing theories, and in turn, existing theories can be used for examining and evaluating new evidence. A theory may be strengthened, abandoned, or replaced depending on how well new evidence supports a theory.

Before elaborating on the relationship between observation, background knowledge, and evidential arguments, I will illustrate the notion of evidence with the following simple examples.

Example 1. A woman and a man are talking about the effects of second hand smoke. The woman claims that second hand smoke is detrimental to an individual's health. The man asks the woman, "What evidence do you have for that statement?"

Depending on her background knowledge, she might have knowledge of the following: the chemical carcinogens in second hand tobacco smoke, the biochemical effects of these carcinogens on an individual's body systems, statistical evidence for relating second hand smoke to asthma and heart disease, the effects of nicotine on the individual's system, and the lung recovery rate from previous exposure to smoke. The nature of the evidence presented depends on the background knowledge of the knowledge claimer. If the woman has a medical background she might stress the importance of the biochemical statistical evidence as it relates to the carcinogens and its effect on the individual's asthma. If she has very little background in biochemistry, biology and medicine, she would have to rely on the doctor who wrote the report as evidence for her knowledge claim. The evidence in this example could be results of statistical data, experimental results, or the word of a person in authority. The woman could create an evidential argument by explaining to the man how the evidence supports the theory that second hand smoke is detrimental to an individual's health. Finally, an example of a knowledge claim could be that cigarettes contain carbon monoxide which is toxic to the human body's cells.

Example 2. A second example will give a different perspective on the notion of evidence. A doctor reads a report that fifteen out of thirty people have become sick and hospitalized after eating in a local restaurant. The first thought that she entertains is a hypothesis that half the people are suffering from food poisoning. Although the doctor does not know for certain, she initially believes this to be the case, based upon the limited evidence available. To be certain of her strong hypothesis or initial theory the doctor seeks out further evidence to support her argument. She asks questions such as "What did the fifteen sick people eat in the restaurant prior to becoming sick?" and "What did the other people who did not get sick eat?" The doctor may also physically examine the sick people to confirm her belief that it was a case of food poisoning. Suppose the doctor learnt that the fifteen people who became sick had eaten fish, whereas, the fifteen people who did not become sick had eaten chicken. Each piece of evidence supports her initial theory that the cause of sickness is food poisoning.

In this example, the doctor first obtains some data which suggests a disorder that could account for the sickness. From the sickness, she infers that some other signs will, or will not be present, and she looks for them. If the absence or presence of the signs falsifies her suppositions, she makes another and submits it for further observations. Eventually an initial theory is made which no new observations falsify. Finally, a diagnosis is nearly always reached by the process of elimination. The doctor must be able to reason from her observations which only background knowledge, experience with the disease, and a retentive memory can give her (Stone, 1966).

In this example the background knowledge consists of the physician's knowledge of salmonella food poisoning, the causes of food poisoning, its effect on the human body system, and the treatment. The evidence involves the physical examination of the patients to determine what the sick people ate, written information (report of salmonella poisoning), and verbal information (questioning the people in the restaurant). The doctor may have developed her evidential argument this way: All the patients had symptoms she recognized as salmonella. Moreover, all thirty people ate at the same restaurant at the same time. The individuals at the restaurant shared everything except the fish and chicken. She concluded that it was the fish that caused the food poisoning. The evidential argument is based on her ability to examine and to evaluate the appropriateness of the evidence and to infer what had caused the problem based upon that evidence. She was able to use a process of elimination, based on her questioning skills and the meaning of the responses, to construct the evidential argument. The knowledge claim, in this example, consists of the physician stating that the fish caused the food poisoning in the restaurant.

Example 3. A third example of the notion of evidence is taken from Williams and Stinner (1992). A physics student and his friend, while visiting an old fort, look down a deep well. The physics student turns to his friend and says: "This well is approximately 32 meters deep, give or take a meter." His friend replies: "How do you know that? Did you read it in a brochure?" The physics student smiles and says: "No, I was here earlier and timed the fall of a heavy rock. Based on that information I quickly calculated the depth of the well." His friend, who has not taken physics but is a good mathematics student looks puzzled and then asks the physics student: "How did you find the time of fall? You cannot see the splash!" The physics student smiles: "Last semester we solved a problem like this in class. Knowing the speed of sound at a given temperature you can set up two simultaneous equations, one involving free fall and the other involving the speed of sound. I kept the algebraic solution in my calculator." He proceeds to drop a stone, measures the combined time it takes the stone to fall and the time it takes for the sound to return, pulls out his calculator, punches in the numbers for total time, temperature, and local gravity, and says: "Yes, about 32 meters."

In this example the physics student's background knowledge in physics consists of understanding two equations: one for free fall and the other involving the speed of sound. He also has to know the temperature and the the local gravity. With this knowledge, he is able to calculate the speed of sound from a falling stone and insert that calculation into an algebraic formula.

The physics student's evidence results from his background knowledge and an experiment which timed the fall of a stone into the well. This experimental evidence can be combined with other evidence obtained from the measurement of local gravity and temperature.

The evidential argument, in this example, involves the physics student's ability to infer, from his background knowledge, the experimental evidence and other evidence, that the depth of the well can be calculated using mathematical equations.

The physics student can make the following knowledge claim: "This well is approximately 32 meters deep, give or take a meter."

It is interesting to note that his friend, unless he has a similar background knowledge in the physical sciences, would probably have to simply accept the physics student's knowledge claim.

Example 4. Finley (1983) uses an example of a geologist viewing a section of rock under a microscope. The geologist may "see" sedimentary particles beginning to undergo metamorphosis and therefore this observation would be significant in understanding the origin of the rock. A novice, observing the same slide, would not likely "see" that the process of metamorphosis had occurred and instead may only observe a configuration of colours, shapes and sizes.

The geologist's background knowledge would include the following: knowledge of geological evolution, ability to use the microscope, ability to recognize striations on the rock, knowledge and recognition of the stages of metamorphosis. Observed striations on the rock surface provide the evidence that the rock had undergone metamorphosis. The initial theory or the "strong hypothesis" of the geologist, in this example, would be: that he could determine the origin of the rock from miscroscopic examination of that rock. The evidential argument, used by the geologist, would include the following: if the rock was undergoing metamorphosis then there would be recognizable striations on that rock and evidence based on this knowledge plus the geologist's background knowledge would result in the geologist's claim about the origin of the rock. The knowledge claim that the geologist stated was: "I know this rock is undergoing metamorphoses and I know that this rock originated from the Mesozoic era". Moreover, the geologist will be able to make a knowledge claim based upon his evidential argument.

The novice, on the other hand, would not share the same theoretical background knowledge and therefore would not recognize the meaning and the importance of the observation or experience. In fact, the novice observer ***would not recognize the observation as evidence.***

Hanson provides insight into the notion of observation or "seeing" in his classic book Patterns of Discovery. He distinguishes between "seeing that" which involves observations with the benefit of appropriate background knowledge and "seeing as" where the appropriate background knowledge is absent (Hanson, 1961). He uses the following example to illustrate his point: "I can make nothing of the Arab word for *cat*, though my purely visual impressions may be indistinguishable from those of an Arab who can. I must learn Arabic before I can see what he sees" (Hanson, 1961, p.16).

Stone reinforces the importance of presuppositions and background knowledge when he argues that:

> a trained observer knows what to look for and what to ignore; in consequence he saw not necessarily more, but more that is important than the untrained person who is merely observant" (Stone, 1966, p.69).

Therefore, individuals, whether they are scientists or non-scientists, may observe the same phenomenon but interpret it differently. How individuals "see" things then depends on their presuppositions and background knowledge.

In summary, what is considered as evidence (and not just meaningless information) will depend on the individual's presuppositions and background knowledge in connection with information that is observed or experienced. Evidence will then be determined by the individual's ability to recognize and select particularly meaningful data from a myriad of data. Moreover, the observer will then be able to build theories by examining and evaluating evidence, by constructing evidential arguments using his/her ingenuity and imagination, and by making appropriate knowledge claims.

My thesis will focus on the relationship between evidence and theory in science textbooks. I am especially interested in investigating how this relationship is used to build evidential arguments and to develop theories in order to make knowledge claims about the world. By examining scientific theories, I will be able to show how textbooks use evidence to build evidential arguments that are supposed to lead to the development of a theory. Therefore it is necessary to discuss the development of scientific theories because they form the foundations that textbooks use to promote knowledge of science to students. However, prior to examining textbooks, I will discuss how scientists develop theories using evidence and evidential arguments.

3.2 Scientist's notion of evidence

Science progresses by way of developing theories which in turn allow scientists to acquire knowledge about how the world works. In this chapter I will examine how scientists develop theories by looking at how they use evidence and construct evidential arguments to support their theories.

The first step involved in theory building is the creation of an initial theory or partially developed theory (p.d.theory) which could also be referred to as a "strong hypothesis"(Duschl, 1990). I argued in the last section that individuals' presuppositions about the world and their background knowledge are essential for the establishment of evidence from observations. Similarly, for scientists the interpretation of observations will lead to the development of a partially developed theory. Initially, of course, there is little evidence to support such fledgling theories, and therefore I have referred to them as p.d. theories. Scientists seek evidence to support their p. d. theory and as more supportive evidence becomes available the p.d. theories evolve into more developed theories and eventually into a fully developed theory.

However, to recognize observations as evidence and to begin theory building, scientists must have some fundamental presuppositions about the world. Moreover, the presuppositions scientists have will determine what they will interpret as evidence (Collingwood, 1962). Indeed, without these presuppositions it would be impossible for scientists to begin theory development. For example, Charles Darwin had to believe in the principle of uniformitarianism as one of his presuppositions about the world to enable him to develop the theory of evolution. This principle states that geological or natural processes were acting in the same manner in the past as they are in the present and that they are sufficient to account for all geological changes (Marvin, 1973). Therefore he, like other scientists, can confidently examine geological fossil records and infer how life existed millions of years ago.

In addition to such presuppositions, scientists must have a background knowledge that will enable them to give meaning to their observations. Darwin's background knowledge included knowledge based on findings in Lyell's book, Principles of Geology (1833), Linnaeus' binomial nomenclature of animals and plants in his book Systema Naturae (1735), and Lamarck's evolutionary theory published in his book, Histoire Naturelle des Animaux (1822).

Scientists must also apply their imagination and ingenuity to make connections between their presuppositions, background knowledge, and the evidence in order to formulate a partially developed theory. Such "big" theories as Newton's theory of gravity, Wegener's theory of continental drift, and Darwin's theory of evolution started off as p.d. theories. In chapter 4 I will trace the evolution of Wegener's theory of drifting and Mendel's theory of inheritance from partially developed theories to fully-fledged theories.

Once scientists formulate their p.d. theories they examine and evaluate evidence in search of support for their theories. To build support for their theories, scientists develop evidential arguments using their scientific thinking. Stinner (1989) refers to scientific thinking, in general, as the context of inquiry which involves scientists asking questions, solving problems, and doing experiments. I will include Stinner's context of inquiry as part of scientists' evidential arguments. These evidential arguments make the connection between the evolving theory and the ongoing development of new evidence which supports this theory. Having created a partially developed theory, scientists go on to strengthen these theories with such ongoing arguments.

To construct evidential arguments, scientists begin by asking major questions. The questions generated, in turn, are dependent on scientists' presuppositions about the world. These presuppositions may include the principle of uniformitarianism which was defined on the previous page. Clearly, without the assumption of the principle of uniformitarianism, Darwin would not have been able to pose the major question of what mechanisms in evolution account for natural selection.

These major questions then immediately lead to problems, which scientists must solve in their search for evidence. The problem for Darwin was to find evidence to support the mechanism of natural selection.

To solve such problems scientists gather evidence by performing experiments. Stone also argues that an experiment is an observation which answers a question. He claims that if the answer supports the theory then it is interpreted as evidence. For example, Mendel's heredity experiments served as evidence to support his theory that "factors" were transmitted from generation to generation (Stone, 1966). Scientists also obtain evidence by gathering data. For example, Darwin systematically gathered data by measuring the anatomical structure of animals and compared the morphological differences among organisms from diverse geographical locations. The evidence generated included the observed length of bird beaks relative to their geographical location.

Such data when analyzed, may present more evidence for supporting partially developed theories. Scientists now create secondary questions. For Darwin one of these questions was: "Are the anatomical structures of birds on the Galapagos Islands morphologically different from those structures of birds on the mainland?" When answers are found to such questions they enable scientists to make knowledge claims. For example, Darwin used the evidence acquired from measurements of birds' beak as a basis for claiming that birds were able to adapt to a specific environment.

These knowledge claims can result in the increase of scientists' background knowledge. Scientists will then be in a position to ask new questions, to create new problems, to do new experiments and eventually to make more knowledge claims. The cycle of inquiry then starts all over again. In other words, scientists can go from background knowledge to knowledge claims and then to new background knowledge by gathering new evidence and constructing new evidential arguments.

It should be stressed however, that scientists must consider all forms of scientific evidence whether supportive or non-supportive of the theory. Scientists who examine and evaluate evidence and find that it does not support the theory, will modify the existing theory, and sometimes even reject the theory. For example, geologists during Wegener's time argued that a glacier had covered the southern continents as well as the vast expanse of ocean. Therefore, they inferred that animals were able to cross from one continent to the next. This argument would then explain why similar fossils had been found on two different continents. Wegener, however, rejected this glacial theory because there was no evidence to suggest that a glacier had covered a vast expanse of ocean and then melted. Another clear example of non-support for a theory was the theory of spontaneous generation which was discarded when scientists found evidence which clearly falsified the theory.

Eventually, if enough evidential support is available and if it strongly supports the partially developed theory, then the p.d. theory may evolve into a fully developed theory. Duschl (1990) argues that theories can be categorized into different levels. *Frontier* level theories (which I refer to as partially developed theories) are based on sound scientific evidence and established explanations. However, these theories have inconsistencies and therefore are incomplete. For example, Wegener's theory of continental drift was based on sound scientific evidence but lacked an adequate explanation for the mechanism which caused drifting to occur. Finally, *central* level theories (which I call fully developed theories) are not only based on sound scientific evidence and established explanations, but are also consistent and therefore complete. Newton's laws of motion are examples of a central level theory.

However, the evolution to a fully developed theory may take many years to accomplish. For example the theory of continental drift was first proposed in 1915 by Alfred Wegener but its final version was not accepted by the scientific community until overwhelming evidence in its support appeared in the late 1950s and early 1960s.

In summary, scientists must begin with presuppositions about the world and with a background knowledge prior to formulating a partially developed theory. Moreover, scientists will then be able to give meaning to observations which, in turn, will serve as evidence to support their p. d. theories. This background knowledge will increase as new evidence becomes available and scientists can develop evidential arguments. Scientists use contexts of inquiry to gather evidence and develop theories. Moreover, evidence leads to knowledge claims and contributes to the building of scientific theories.

Therefore, how science textbooks present the notion of evidence to students becomes an important factor in students' ability to understand the scientific enterprise.

To show how scientists' evidence contributes to the evolution of scientific theories, I will examine the development of two partially developed theory into fully-fledged theories. The first example is the evolution of Wegener's theory of continental drift to the contemporary plate tectonics theory. The second theory is the evolution of Mendel's original theory of inheritance to present day gene theory.

Chapter 4
Theory Development

4.1 Wegener's continental drift theory and plate tectonics theory.

In this section I will examine Wegener's theory of continental drift. I will follow the development of a fully-fledged theory from its infancy to its maturity. Wegener's theory was chosen because it clearly demonstrates the relationship between evidence, an evidential argument and the evolution of a theory. Moreover, this theory is a clear cut example of how scientists use evidence to construct a fully-fledged theory that can be understood at the grade eight and nine level in science.

To fully understand Wegener's theory, I must start by examining the scientific paradigm that was used by geologists, which existed prior to the theory of continental drift. The geological theory, prior to Wegener, proposed a solid earth concept and therefore could not accommodate a theory of drifting continents. Geophysicists and geologists believed that the earth had been formed in a molten state, cooled, and was solidifying and contracting thus forming a rigid outer crust. This cooling and contracting was thought to be created by compressive forces that, at intervals, along the weak margins of the continents or in the deep basins of soft sediments, squeezed up mountains. Moreover, the pressure from the contractions caused some regions of the surface to collapse and subside, causing the great ocean basins.

Such a theory of contraction seemed plausible to the geologists and the geophysicists because it could explain why vertical movements exist creating mountains and oceans existed (Hallam, 1975; & Wilson, 1963). However, this theory did not answer such questions as why the distribution of the land and seas was asymmetrical in shape and why they were located at certain places on the surface of the earth. Moreover, geologists were puzzled by the question of why the continents existed at all. According to physical theories, the rotation of a planet with a powerful gravitational field such as the earth should create a smooth, featureless surface and should be covered by water (Marvin, 1973).

Geologists tried to explain other puzzling phenomena in the context of a solid earth theory, such as the similarities and recognition of identical fossil plants and animals that were found to exist on different continents. Geologists accounted for this phenomenon by proposing that land bridges had once connected the continents together and the animal species had crossed these bridges to new continents. However, they inferred that these bridges had sunk to the ocean floor and argued that this was the reason why no evidence for land bridges existed. Geologists also attributed the stratification of fossils in the sedimentary deposits to the successive marine transgressions onto the continents from the oceans and the regressions from them into the oceans (Hallam, 1975).

Wegener struggled with the same major questions which had puzzled geologists who had theorized that the continents and ocean basins were one and the same structure. He found many contradictions in the contraction theory and he also found features of the earth's surface that could not be explained by this theory. These contradictions and unexplained events included: the similar "fit" between the continents of Africa and South America, the pattern of distribution of mountain belts on different continents, and data which seemed to suggest two distinct levels in the earth's crust (Hallam, 1975; & Marvin, 1973).

In 1915 Wegener published his theory in **The Origins of Continents and Oceans**. After viewing an old map of the world, Wegener fit the continents together and shortly after he formulated a partially developed theory that the earth's continents were once joined together in a single land mass and that they had drifted apart. The similarity of continental outlines was not a new concept because this phenomenon had been observed by Francis Bacon as early as 1620. However, the idea that the continents were one great land mass was not envisioned at that time. As early as 1858 it was proposed that continents moved but this movement was attributed to a catastrophic event called the Great Flood (Hallam, 1975; Marvin, 1973; & Hurley, 1968).

I must first examine Wegener's presuppositions about the world and his background knowledge in order to make sense of the evidence and the evidential argument that Wegener used to develop his continental drift theory. Then, I will examine Wegener's context of inquiry which involves the examination of major questions that he asked, problems that he solved, experiments that he analyzed and secondary questions that he asked.

Prior to formulating his partially developed drift theory, Wegener accepts the following presuppositions about the world. His first assumption was that the world can be described by the **principle of uniformitarianism**. This principle as originally described by the geologist Charles Lyell, states that scientific processes of the present operate in the same manner as they did in the past and that they are sufficient to interpret the earth's geological history (Marvin 1973). For example Wegener inferred, based on his presuppositions, that observation of similar glacial till on two different continents was evidence for his theory that continents were once joined as a single continent. A second assumption he made was that the asymmetry of the seas and continents can be described in terms of Newtonian physics and the laws of thermodynamics. His third assumption was that drift could be explained by the **principle of isostacy.** This principle which is attributed to Clarence Dutton in 1889 states that the general equilibrium in the earth's crust is maintained by equal pressure from overlying rock masses on rock material beneath the surface of the earth (Marvin 1973). Therefore, the continents, which are less dense than the layer underneath them, will float above the ocean (Hallam,1975).

Wegener needed to combine his background knowledge with his presuppositions about the world so that he would be able to give meaning to his observations. This background knowledge included Newton's laws which could explain the forces required to create continental movement, mathematics that could predict the distance continents had moved over time, and the laws of thermodynamics that could explain continental movement based on the heating and cooling of the earth.

Wegener then asked major questions which were generated from his presuppositions about the world and his background knowledge combined with his observations and experiences. These major questions were:

1.) What physical forces account for the asymmetrical shape and location of the continents and the oceans?

2.) If the continents can move vertically, why can't they move horizontally as well?

3.) What geological evidence supports the theory of continental drifting?

4.) What mechanism can explain this horizontal drifting movement? (Marvin, 1973; Hallam, 1975; & Wilson, 1963).

Once Wegener had formulated his major questions, they would generate specific problems that he would have to solve in order to develop his theory for continental drift. These problems included:

1.) To find a plausible physical mechanism and forces to account for horizontal drifting of the continents.

2.) To find evidence from palaeontology and palaeoclimatology to support the continental drift theory.

3.) To describe a theory which will explain continental drifting.

4.) To determine if the planet consists of two distinct levels (Marvin, 1973; & Hallam, 1975).

To find answers to his questions and solutions to his problems, Wegener, looked for evidence to further develop and support his partially developed theory. Wegener then used his ingenuity and imagination combined with his evidence to develop an evidential argument in support of his theory.

Initially, Wegener based his partially developed theory on the evidence provided by the reconstruction of old maps. He observed the outline of the continents and respectively placed them together as one large land mass as one would fit jigsaw puzzle pieces together. Although there was not a perfect fit, Wegener thought that there was a good enough fit to add support to his theory that the continents had been once joined together as one large land mass. This partially developed drift theory also explained why the continents appeared asymmetrical in shape on a world map and why there is a similarity in continental outlines (Marvin, 1973).

Next, Wegener hypothesized that the continents and the ocean floors were fundamentally distinct from one another. He based this hypothesis on statistical evidence obtained from the analysis of the earth's topography. Mathematical calculations of the total area of the earth's surface at different land elevations and ocean depths indicated to Wegener that the earth's crust consisted of two distinct levels. The first level corresponds to the surface of the continents and the other to the abyssal sea floor. His idea of two levels was supported by measurements of local variations in the earth's gravity (the lower sea level had a greater mass than the continental regions). If the earth was only one level, as believed by geologists, then elevations should be distributed around a single median level. The idea of two distinct levels fitted with Wegener's belief in the principle of isostacy, that is, that the continents being less dense than the ocean floor would therefore float above the ocean floor. Wegener's view of two distinct levels was not consistent with previous geological interpretations. Geologists believed that the earth consisted of one level and variations in elevation were the result of random uplifting of the earth's surface (Hallam, 1975; & Marvin, 1973).

Another source of evidence for his argument of continental drift came from a report of fossil records from South America and Africa. These records showed that fossil animals of the same geological age were present in restricted habitats on two seemingly unconnected continents. Paleontologists at that time proposed that the continents had at one time been connected by land bridges and this is how the animals were able to migrate from one continent to the next. Wegener could not envision how animals could have transported themselves across the ocean to evolve similarly and at the same time since their was no geological evidence of land bridges. Also, according to the principle of isostacy, land bridges, being on the upper continental level, should be less dense than the lower ocean level, and therefore the land bridges should float and the evidence for the existence of these bridges should be present. Wegener reasoned that if the fossil records were the same age and similar in appearance and if there was no evidence of land bridges, then there had to be one large land mass where these fossils originated and these land masses eventually drifted apart over millions of years (Marvin, 1973).

Further evidence for continental drift was found by Wegener when he examined geological rock structures located on different continents. These structures included faults and rock types that were the same age, had similar lithologies (rock strata) and also had similar rock orientation on the continents of North America and Northwestern Europe. Moreover, these structures stopped at the edge of the continent and then continued on the next continent across the ocean. Wegener inferred from these rock structures that the continents were one great land mass (Marvin, 1973).

The next set of data was found when Wegener used records of geodetic evidence (applying mathematical techniques to determine, by observation and measurement, the exact positions of points and areas of large portions of the earth's surface in relation to the curvature of the earth) of longitude and latitude to show that Greenland and other continents are moving at a substantial rate (Hallam, 1975).

More evidence to support his theory became available when Wegener used his background knowledge in climatology to examine paleoclimatic reports. He found evidence of glacial deposits in the form of glacial till on the continents of South Africa, South America, India, Australia and Antarctica. He inferred from these glacial reports of striated and grooved bedrock that the continents in the southern hemisphere were once one great land mass. Moreover, this evidence suggested to Wegener that the continents in the southern hemisphere had been further south than their "present" position ("present" refers to Wegener's time) (Hurley, 1968). Wegener also reasoned that there was not enough water to create a freshwater glacier large enough to span the oceans to the present position of the continents. More palaeoclimatic evidence became available when Wegener found fossil ferns in North America. From his background knowledge in climatology, he knew that these fossil ferns were indigenous to tropical, swampy climates. He therefore inferred that this land mass must have been further south than its present position. Thus the paleoclimatic evidence suggested to Wegener that, in addition to continental drift, polar wanderings had occurred (Hallam, 1975).

Generally, to obtain evidence and develop evidential arguments, scientists do experiments or refer to experimental results from other scientists. These experiments are generated from major questions and from problems that were encountered. However, Wegener himself did not conduct any experiments. He relied instead on examining other scientists' reports of what he considered relevant experiments. He then systematically gathered data such as palaeobiological records of fossils on different continents.

The results of these experiments, together with reports and systematically gathered data allowed Wegener to make important knowledge claims. For instance, he claimed that the fossils on the European continent were the same age and identical to the fossils found on the North American continent.

Finally, new evidence from observational data and experimental reports by other scientists would produce minor questions for Wegener. These questions included:

1.) What other paleological evidence supports the theory of continental drift?

2.) Did land bridges exist and did the glaciers spread across the oceans?

3.) What evidence supports the proposed mechanisms (i.e. gravity) for continental drift? (Marvin, 1973).

Unfortunately, Wegener could not present evidence or an adequate evidential argument to convince geologists to accept his theory, and therefore it was not widely accepted as a fully developed theory in the geological community. Even with all the evidence to support the continental drift theory it was rejected by many geologists. One of the problems that Wegener had difficulty in solving was providing an explanation of the force required to cause the continents to drift apart. Geologists countered Wegener's arguments by asking him for the force which caused continental drifting. Wegener proposed that the forces which caused drifting of the continents can be attributed to the earth's rotational system and the effects of gravity. One force, as described by Wegener, was "centrifugal" force which, due to the earth's rotation, impels the continents towards the equator and he referred to this movement as polar wanderings. Another force, he thought was the gravitational tidal attraction of the sun and moon They exert a drag on the crust, slowing its rate of rotation, which causes the continents to drift away from one another. One of the greatest attacks on Wegener's proposed forces came from a geologist's calculation that mountain ranges would collapse under their own weight and the sea floor would be perfectly flat if these forces existed. Wegener was unable to provide an acceptable hypothesis for such a mechanism. Had he been able to provide an explanation and the evidence to support that force, then he probably would have had a fully developed theory that would have convinced other geologists.

Another reason why geologists rejected Wegener's theory was that they believed his theory was based on a **catastrophic** event even though Wegener's theory was based on the assumption of the principle of **uniformitarianism**. Wegener proposed that continental drift occurred only once over a few million years and this time frame was very short in comparison to the age of the earth. Geologists who were uniformitarians believed that continents had never drifted. Moreover, geologists were firmly entrenched in the solid earth theory. Therefore, new continents could be uplifted from sea floors but they could not move from one part of the earth to another as proposed by Wegener (Marvin, 1973).

Wegener's theory was hotly debated for years until the late 1950s and the early 1960s when great advances in the technology of mapping the ocean floor, paleomagnetism and seismic activity provided strong supporting evidence for the continental drift theory. Precise scientific instruments were developed to help geophysicists map and collect accurate data from the sea floor. They discovered that the ocean floor consisted of mid-ocean ridges, rift valleys and deep sea trenches. Moreover, they discovered that the youngest rocks were found at the mid-ocean ridges while older geological rock formations were found towards the continents. The difference in the geological ages suggested to geologists that the continents were being formed from younger rock moving from the mid-ocean ridges towards the older rock continents. In 1962, Harry Hess published a paper entitled History of Ocean Basins where he argued that the ocean floors were being constantly renewed by magma flowing up from the the ocean rifts. He thought that the magma was spreading out laterally from these rifts towards the continents. Hess's hypothesis eventually became known as the sea-floor spreading theory. Unfortunately, this theory, like Wegener's theory, could not provide an answer as to the force which caused continents to move. However, the sea floor spreading theory was strong evidence for Wegener's drift theory (Marvin, 1973).

Evidence that provided strong support for Hess' sea-floor spreading theory and the continental drift theory was discovered in the 1960s when scientists using shipboard magnetometers found that areas of the ocean floor were magnetized in a stripelike pattern as the magma moved toward the continents. These patterns indicated that the polarity of the magnetic fields had globally reversed at certain fixed times in the history of the earth and geophysicists were then able to determine the age of the rock by the direction of its magnetic field. They found that the rock was oldest near the continents and youngest near the mid-ocean trenches. This evidence indicated that movement was occurring from the mid-ocean trenches towards the continents and the oceanic ridges and rifts were the site of rising and spreading rock material. Magnetic strips of polarity were coming from mid-ocean ridges and scientists could determine the age of magnetic rock by radioactive dating techniques. It was then possible to date ocean floors and determine the direction and rate of their lateral movement by conducting magnetic surveys over them. Geophysicists could also determine the rate of flow by applying the simple formula: D= r x t , where "D" equals distance rock moves, "r" equals the average rate the rock moves and "t" equals time in millions of years that was necessary for the rock to move that distance at that rate. In 1963 this information provided strong evidence that the ocean floor was spreading out towards the continents and therefore confirmed the continental drift theory (Hurley, 1968).

Also during the 1960s, **paleomagnetic evidence** strongly supported the continental drift theory. Geophysicists discovered that iron bearing rock becomes slightly magnetized, when it is formed, in the direction of the earth's magnetic field (N/S direction). Therefore, the direction of polarity for each continent could be determined by measuring the magnetism of the rocks from similar geological age periods on different continents. They found that the magnetic pole was different for each continent and if geophysicists assumed that the magnetic pole did not wander from the axis of the earth's rotation or the axis hadn't changed position with respect to the principal mass of the earth, then they could conclude that the continents must have moved over the surface of the earth. The paleomagnetic evidence not only supported the notion of continental drift but also indicated the general locations from which the continents had moved within an appropriate time span (Hurley, 1968; & Marvin, 1973).

With paleomagnetic evidence, geophysicists determined the rate and direction of sea floor movement. Moreover, they were able to categorize the ocean floor and the continents into twenty rigid segments which they called plates. They then postulated that each plate moves as a unit in respect to other plates and they also interact when they come into contact with each other. This movement of the plates was called the **plate tectonic theory**. This theory proposed that the earth consisted of rigid blocks of the earth's upper crust and upper mantle which was called the lithosphere. Below the lithosphere was a layer called the asthenosphere which was a plastic like zone near the melting point. The lithosphere being less dense floated on and moved over the asthenosphere. However, geophysicists could not adequately explain and find evidence for the driving mechanistic force for plate movements. Nevertheless, they proposed an initial theory that the force is generated from the unequal distribution of heat in the earth's interior. Scientists found that the plate tectonics theory could predict and explain such diverse phenomena as earthquakes, volcanoes, mountain range formation, seafloor spreading and fault zones.

The strength of the supporting evidence after Wegener first proposed his continental drift theory enabled his theory to go from a partially developed theory in 1915 to a fully fledged theory in the mid 1960s. Initially the evidence was not adequate to convince most geologists to support Wegener's theory. However, by 1968 all geologists supported Wegener's continental drift theory (Marvin, 1973).

Although the continental drift theory has not been outlined in detail, I have sufficiently shown the steps involved in changing a partially developed theory into a fully developed theory. Moreover, my example of theory development also illustrates how evidence and a corresponding evidential argument is essential in developing a theory. As more evidence becomes available, more questions and problems are generated, more experiments are generated and more answers about how the world works comes about. In addition, scientists' background knowledge increases and new theories that explain and predict how the physical world works, evolve. Thus science grows through knowledge acquisition together with the development of theories. In the example of Wegener's continental drift theory, the evidence which supported his theory only allowed Wegener to formulate a partially developed theory. However, as new evidence became available a "big" theory such the plate tectonics theory evolved.

To illustrate the evolution of another theory, I will examine the development of the gene theory. I have chosen the gene theory because it has a developmental history that is significantly different from the continental drift theory and the plate tectonics theory. The gene theory is also taught at the grade nine level. I will look at the theory starting from Mendelian laws of inheritance in 1865 to the discovery of the D.N.A. model in 1953. The major emphasis will be placed on Mendelian genetics and the D.N.A. model will be mentioned only briefly.

4.2 The gene theory[1] from Mendelian heredity to the D.N.A. model.

I will define the gene theory as a theory which proposes a mechanism responsible for heredity. This theory will be outlined starting from a partially developed theory which originated from Mendelian heredity and concluded as a fully developed theory with the discovery of the D.N.A. model.

The gene theory is similar to the continental drift theory in that both are examples of the evolution of a fully developed theory by scientists examining evidence over a long period of time. Both theories were revolutionary theories that were rejected when they were initially proposed but were later accepted as more supportive evidence became available. Moreover, and importantly, the evolution of these theories can be followed by students at the grade eight and nine levels.

The development of the gene theory, however, is significantly different from the development of the continental drift theory. The gene theory relies mainly on Mendel's experimentation and his interpretation of these experiments to develop evidence and evidential arguments. The continental drift theory, on the other hand, relies not on experimentation but rather on interpretation of a systematic collection of diverse data as evidence.

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[1] The name gene theory was taken from E. Carlson's book (1967): Gene theory: an historical view, Belmont, California: Dickenson.

I will begin by describing Gregor Mendel's heredity experiments. Mendel was influenced by previous studies in heredity which were principally concerned with horticulture and animal breeding. These studies concentrated on observations which were based upon practical experiments and little importance was placed on the theoretical aspect of how heredity worked or on the underlying mechanisms of heredity. Mendel, however, was interested in the mechanism that would explain heredity. He provided the link between the practical knowledge of horticulture and the theoretical knowledge of biology (Jacob, 1974). To make that link, Mendel had the following presuppositions about the world:

1.) organic forms were evolving in the world;

2.) the characteristics of heredity could be explained by physical and mathematical laws that governed nature.

Mendel's presuppositions that heredity could be explained in physical and mathematical terms were a radical departure from the anatomical and physiological explanations of heredity by scientists at that time (Jacob, 1974).

Mendel also had to have a background knowledge in physics, mathematics and plant physiology which he could apply to the study of heredity (Huckabee, 1989; Jacob, 1974; & Carlson, 1967).

With these presuppositions and background knowledge in mind, Mendel, in his search for the mechanism to explain heredity, asked the following major questions:

1.) What mechanism governs the development of hybrids and their offspring and how can the different types of hybrids be described in each generation? (hybrids are defined as the offspring of the parents)

2.) How can the different "forms" be arranged with certainty according to their separate generations? (Mendel referred to forms that the plants displayed from the fertilization process)

3.) How can the statistical relations of "characters", in each generation, be expressed? (Mendel defined characters as the observable traits of the plants, i.e. long stems)

4.) Do "characters" segregate randomly in each generation and do "characters" express themselves equally, generation after generation? (Peters, 1959; Jacob, 1974; & Carlson, 1967).

These major questions immediately led Mendel to examine the following problems:

1.) To determine the laws governing the formation of hybrids,

2.) To determine constant differentiating characters (i.e. dominant & recessive),

3.) To arrange these characters with certainty according to their separate generations,

4.) To discover if segregation of characters is a random process,

5.) To express characters of each generation statistically and symbolically,

6.) To invent a suitable notation to predict characters of crossings (Peters, 1959; & Jacob, 1974).

To answer his questions and to solve the ensuing problems, Mendel spent the next eight years doing experiments to collect evidence. Mendel's experiments were designed to reveal what other experiments of heredity had failed to recognize. The experiments were intended:

1.) to determine the number of different forms in which the offspring of the hybrids appear,

2.) to arrange these forms with certainty according to their separate generations,

3.) to ascertain statistical relationships of the forms (Peters, 1959).

Mendel's background knowledge in mathematics and physics allowed him to approach his experiments in the following novel way:

1.) He designed experiments by choosing appropriate experimental material and introduced the concept of discontinuity into his experiments

2.) He experimented on a scale so that individuals can be ignored and only populations are taken into account.

3.) He expressed the population results numerically.

4.) He treated the results mathematically.

5.) He followed the behaviour of characters in a long series from generation to generation. And finally,

6.) He used simple symbolism to represent genetic traits (Peters, 1959 & Jacob, 1974).

Mendel's novel ways permitted a continuous interchange between experimental results and theory (Jacob, 1974). These experiments were based on crossing different characters of plants and then *observing* the results at each generation. His first two years were involved with experiments to find the plant most suitable for the study of heredity characters. He eventually chose the genus *Pisum* of the pea family because its characters were easily recognizable and the pea plants were easy to cultivate. In addition, they had a short period of growth, they had a limited number of traits which varied distinctly, and when the hybrids were artificially fertilized they yielded perfectly fertile progeny. Moreover, foreign pollination could not easily occur due to the close proximity of the fertilizing organs in the pea plant. This self fertilization ensured purity of the characters in each generation and also enabled Mendel to determine which characters were passed on from generation to generation (Peters, 1959).

In his early experiments, Mendel crossed varieties of pea plants which differed in only a single character, i.e. length and of stem, (short stalk crossed with a long stalk or the form of the seeds). Mendel observed, from these crossings, that the first generation hybrids resembled only one of the parents and never the other. Those characters that were transmitted entirely into the first generation hybrids and constituted the characters of that hybrid, Mendel called *dominant* characters. Those characters that were not expressed in the first generation hybrids but reappeared in the progeny, he called *recessive* characters. Mendel attributed the biological basis for these observable characters to what he called "internal elements". Moreover, these internal elements constitute, he thought, the "factors" of heredity which could be independent of one another and each could determine an observable character (Peters,1959 & Jacob, 1974).

The careful selecting and crossing of single characters, in his experiments, provided Mendel with a novel way of expressing the results. Due to Mendel's deliberate introduction of discontinuity into the discrimination of characters, it was sufficient for him, in each generation, to count only the number of individuals of each class. Moreover, each class could then be assigned a whole number and, in turn, these numbers could be treated statistically and the results expressed as a ratio. By this method, Mendel was able to determine the numerical ratio of the dominant character to the recessive character (3 dominant characters expressed to 1 recessive character) (Peters,1959 & Jacob, 1974).

In his next experiments, Mendel crossed the hybrids which produced offspring that resulted in half developing into the hybrid form while the other half yielded offspring which remained constant and received the dominant or the recessive character in equal numbers. From the observed results of his crossing experiments, Mendel proposed that if the organism comes from the pollen or the egg cells there must be pure and constant heredity lines which have the same character and can be denoted in symbol form. This symbolic denotation of the results represented the link, for Mendel, between the theory of heredity and the observed experimental results. For example Mendel denoted the following symbols to represent the specific hereditary characters: ***A*** represented the dominant character in the pollen and egg cells , ***a*** represented the recessive character in the pollen and egg cell, and ***Aa*** represented the hybrid form in which equal number of pollen and egg cells (***A*** and ***a***) are joined. Mendel inferred, based on his knowledge of the law of probability, that each pollen cell ***A*** and ***a*** will unite equally often with the egg cell ***A*** and ***a*** to form the hybrid ***Aa.*** The equal probabilities of crossings can be expressed as follows:

- pollen cell ***A*** will unite with egg cell ***A*** or ***a***
- pollen cell ***a*** will unite with egg cell ***A*** or ***a***

Mendel then applied mathematical techniques, which will be explained later, to predict the characters of the offspring. The resulting mathematical expression ***A+2Aa+a*** could be used to represent the terms in the series of progeny of the hybrids of two different characters. The ratio of dominant characters to recessive characters is 3:1 and the ratio of pure strain to hybrid strain can be expressed as 1:2:1(Peters, 1959 & Jacob,1974).

Mendel superimposed a whole internal logic on heredity with his methodology, statistical treatment and symbolic representation of the characters (Jacob,1974). Moreover, these interpretations permitted Mendel to formulate hypothesis from the observed distributions of characters and also it led to predictions which could be experimentally tested.

Once the ratio of crossing single characters was established by Mendel, he could then determine theoretically, using a simple mathematical formula, what the ratios would be if two or more different characters were crossed from generation to generation. His mathematical formula for ***predicting*** the outcome of crossing several characters in the parental generation (i.e. length of stem, form of seed, colour of seedcoat and form of pod) is expressed as follows:

n symbolizes the number of differentiating characters in the two original parents (n=4).

2n equals the number of unions which remain constant (2n=16).
3n equals the number of terms of the combination series (3n=81 classes).
4n equals the number of individuals which belongs to the series (4n=256 individuals) (Peters, 1959 & Jacob, 1974).

To test his predictions Mendel experimented with plants which differed in two or more characters and compared the observed, experimental results with his theoretical results. Mendel was able to confirm, through experimentation, that his theoretical predictions were correct (Peters, 1959).

Mendel's discovery, however, had no impact on the scientific community. His concept of discrete hereditary units, the statistical analyses of these units and the symbolic representation of biological characters was not accepted by biologists. They adhered to their paradigm of anatomy and physiology as the basis of heredity which was prevalent in the mid to late 19th century. Mendel's statistical interpretation of his experiments was entirely foreign to the way of thinking of biologists until the beginning of the 20th century (Stent, 1972).

Biologists still adhered to the Darwinian theory of ***pangenesis*** which stated that "each fragment of the body, each cell, produced a germ of itself, or a *gemmule* that was sent to the germ cells and commissioned to reproduce the same fragments in the next generation". Darwinian heredity offered no distinction between the "body of the parents, their seed, and the body of the child"(Jacob, 1974 p.206). Mendelian heredity not only contradicted

Darwin's theory but also went further to state that heredity could be analysed by physical and mathematical laws (Jacob, 1974).

The gene theory was strengthened when more evidence became available in 1900. Scientists began focussing more on cytological studies of the cell and discovered the existence of chromosomes by carefully observing the mechanism of cell reproduction. In fact, scientists proposed a partially developed theory which claimed that heredity was attributable to the transmission of a particular chromosomal "hereditary substance" from generation to generation. This p.d. theory became known as the chromosome theory. Scientists could now apply simple mathematical techniques to show how this "hereditary substance" could be passed on from generation to generation. Moreover, hereditary characters could then be traced back generations by applying statistical laws to biology. These discoveries in heredity were evidence which supported Mendel's experimental results and explanations of heredity, which had been ignored for thirty five years(Stent, 1972 & Jacob, 1974).

More evidential support for the gene theory came from H. de Vries's discovery of mutations in 1900, and T.H. Morgan's experiments in 1910 which found that in each successive generation specific genes were sex linked. Further mutation experiments plus additional chromosomal mapping experiments by other scientists provided additional evidence to support the theory that the chromosomes were responsible for heredity (Peters, 1959; Allen, 1978; Jacob, 1974; & Carlson, 1967).

The final evidential support for the gene theory was discovered from 1920 to the early 1950s when D.N.A. was found to be the major component of the chromosomes. The strongest evidence for the gene theory occurred in 1953 when the double helix structure of D.N.A. was first constructed by J. Watson and F. Crick. Essentially they used trial and error experimentation, based on the the latest evidence, to built a scale model of the D.N.A. molecule (Peters, 1959; Crick, 1954; Carlson, 1967; & Stent, 1972).

This outline of the gene theory is a good example of how scientists, like Mendel, made presuppositions and how background knowledge played a key role in their ability to make inferences from the evidence they observed. Moreover, the gene theory shows how supporting evidence strengthened the evolution of a partially developed gene theory (starting with Mendel's experiments) to a fully developed gene theory (concluding with the structure of D.N.A.).

In the next chapter I will examine how science textbooks discuss the evolution of the continental drift theory and the gene theory using the scientists' notion of evidence.

Chapter 5

Science Textbooks and the Reporting of the Notion of Evidence:

In the previous chapters I have tried to show that what counts as evidence is related to scientists' presuppositions about the world, their background knowledge, the evidence and evidential arguments, and finally to their knowledge claims. To illustrate the general notion of evidence, I have outlined the evolution of Wegener's continental drift theory and Mendel's gene theory.

I have now arrived at the central purpose of this thesis, to examine how science textbooks present to students, in the middle years, the evolution of scientific theories. To accomplish this task, science textbooks will be examined in two different ways. First, I will examine how science textbooks teach the notion of evidence that scientists use to develop their theories. To this end textbooks will be analyzed to determine how they report scientists' background knowledge, their presuppositions about the world, their observations, the evidence and evidential arguments that are established, the theories that are developed, and the resulting knowledge claims made.

Second, I will examine the evidence, evidential arguments, and knowledge claims, which are constructed by textbooks themselves and that are not attributed to a particular scientist. For example, textbooks might state a general <u>theory</u> that dinosaurs became extinct due to the effects of a large meteorite striking the earth. For evidence textbooks then may report findings of a meteorite impact, data from radioactive dating techniques to determine the age of the rocks and the age of dinosaur bones, and even climatic changes at the time of impact. In addition, science textbooks may build an evidential argument by making inferences based on this evidence. For example, textbooks may infer from the evidence that dinosaurs became extinct at the same time the meteorite struck the earth. The knowledge claim then reported by the textbook may state that dinosaurs existed on earth millions of years ago and they became extinct due to a meteorite impact.

Finally, I will examine how science textbooks report other sources as evidence which I will call pedagogical evidence. This evidence includes:

1.) Evidence as an appeal to authority. Kilbourn (1970), categorized an *appeal to authority* as evidence to support a knowledge claim. Textbooks often report scientists' knowledge claims as the only source of evidence. For example, the claim may be made that all scientists generally believe that the earth is spheroid in shape. However, textbooks generally do not discuss the basis of this claim for the benefit of students. Therefore, students will have to accept these knowledge claims based solely on scientists' authority. Most students, however, will accept the knowledge claim of sphericity on the basis of a statement by a scientist only. Scheffler (1965), argues that the teacher's knowledge claims can also be the only source of evidence. Scheffler claims that if students believe what the teacher claims without examining the evidence, then unfortunately, their only evidential case becomes an appeal to authority. Rogers (1982) also questions the appeal to authority as the only source of evidence to support a knowledge claim. He uses an example to illustrate his point: "If Johnny 'knows' *X* merely because the teacher (or the textbook) tells him it is true, the question arises: How does the teacher (or the textbook) know ? The only 'authority' answer which can be given is that *his* teacher told him; and *that* the teacher in turn must merely have been told by *his* teacher....and so on. To rely upon 'knowledge on authority' as the *sole* criterion is to slide helplessly into the absurdity of infinite regression" (Rogers, 1982, p.2).

Clearly, it is not possible for the textbook to present evidence for every knowledge claim. Some knowledge claims must be accepted on authority. However, when textbooks are reporting the development of a theory, it should be their responsibility to present sufficient evidence to convince students. Students will then have an opportunity to examine and evaluate the evidence. However, it is not always possible to present students with direct evidence, especially in textbooks (Kilbourn, 1970). For many knowledge claims in science only indirect evidence is available. Therefore, indirect evidence will have to suffice to students, as support for a theory. For example, textbooks could provide evidence that supports a spheroid earth theory by including pictures from outer space, suggesting scientific experiments using large spherical balloons and using a globe and flashlight. Even mathematical evidence can be used such as Eratostenes's calculations to determine the size of the earth.

2.) Evidence in the form of pictures, data tables and graphs. Textbooks often use pictures, tables and graphs as evidence to support a theory. For example, textbooks show pictures of Earth from outer space and then make the claim that the picture is the conclusive proof that the earth is spheroid in shape. Unfortunately the picture is the only evidence the textbook uses to support the claim that the earth is spheroid in shape.

The textbook may use tables as evidence. For example, the textbook may show calculated data of the polar circumference and the equatorial circumference. The observed differences in circumferences serve as evidence to support the textbook's claim that the earth is not exactly spherical in shape (Bishop, Lewis, & Sutherland, 1976).

3.) Evidence in the form of algorithms and exemplars. Textbooks can use algorithms and exemplars as a source of evidence to support a theory. An algorithm is defined as a finite set of steps that leads to solving certain problems (Webster's New Collegiate Dictionary, 1976). For example, students may be asked to solve the problem by determining the valence of a resulting compound when two elements called **X** and **Y** with valences of +2 and -3 respectively are chemically combined. The solution provided for students, by textbooks, is a series of well defined steps which includes: first, the cross multiplication of **X** element with **Y** element and second, the disregarding of the signs. Therefore, the results are X_3 and Y_2 when these elements combine. Students can then solve this problem by using an algorithm. This algorithmic solution may be used to support the experimental results when elements X and Y chemically react and they are observed by students.

An exemplar is defined as "concrete problem-solutions that students encounter from the start of their scientific education, whether in laboratories, on examinations, or at the ends of chapters in science textbooks" (Kuhn,1970, p.187). A simple example of an exemplar is the testing of the probability theory and applying the results to genetics. Students may be asked to flip a coin 100 times to determine the frequency of heads landing upright as opposed to the frequency of tales. Students would then be required to calculate the probability of the number of heads as opposed to the number of tales. These calculations may then be used to demonstrate the law of probability. Students would then be asked to apply this law to mathematically calculate the ratio of crossing two independent variables in genetics. Students could be given other problems in genetics that required the use of the law of probability.

Thomas Kuhn argues that exemplars, that is, "the concrete problem-solutions that students encounter from the start of their scientific education, whether in laboratories, on examinations or at the ends of chapters in science texts" is "learning consequential things about nature" (Kuhn, 1970, p.187). Therefore, textbooks are successful in producing students who are competent problem solvers in "normal" science.

However, Stinner (1992) argues that although Kuhn is right when he says that ideally students should make connections with the evidential base by doing exemplars, in reality, students fail to make these connections with this plane. As a result the normal pattern of learning is still memorization and algorithm-recitation. 4.) Evidence in the form of experiments. Textbooks often present experiments to support a theory. For example, students may be asked to collect data, or the textbooks might give the students the data. Students are then asked to interpret this data. For example, students are asked to observe the moon beginning two days after a new moon. They must draw the observed moon on a chart that is marked into divisions from the horizon. The moon must be placed in the correct position and observed for two weeks (Bishop, Lewis, & Sutherland, 1976). These observations serve as evidence to support the theory that the moon rotates on its axis and that it orbits around the earth.

To help students understand science it is imperative that textbooks report what scientists count as evidence as well as offering reports of its own scientific evidence (not attributed to a particular scientist). Moreover, the textbook has to reinforce the reported scientific evidence with its own pedagogical evidence. Only then will students have an opportunity to examine, evaluate and understand the evidence associated with the development of a scientific theory. Without this opportunity students will have little chance to understand the growth of scientific knowledge.

5.1 Criteria for textbook analyses

I will analyze science textbooks by examining and evaluating how evidence is presented to students. My arguments in previous chapters suggest that I use the following criteria:

1.) Background Knowledge (b.k.):

I have previously argued that the notion of evidence is connected to scientists' use of presuppositions about the world together with their background knowledge (b.k.). These presuppositions and background knowledge are essential to give meaning to their observations. Observations, then are selected according to a point of view, and serve as evidence to help scientists construct an initial theory or support an already existing theory. In the beginning, however, scientists will only be able to construct an initial or partially developed theory (p.d. theory). As stronger supportive evidence becomes available, theories are strengthened and can eventually evolve into fully developed theories (f.d.theory).

An excellent example of theory evolution is Wegener's continental drift theory. To construct his p.d.theory, Wegener first combined his presuppositions and background knowledge to make sense of his initial observations. For example, Wegener was able to apply the principle of isostacy (previously explained in chapter four) to make sense of statistical data from measurements of the earth's topography. He was then able to infer that there were two levels in the earth: an abyssal sea floor level and a continental level. Wegener's p.d. theory did not become a fully developed theory until more evidence became available and scientists proposed the theory of plate tectonics in 1968.

In order to discuss the notion of evidence in a textbook, the textbook writer should first introduce the scientist's presuppositions about the world and the background knowledge. Without this introduction, students reading the textbook will not understand what scientists considered as evidence. To determine if the textbook introduces scientists' presuppositions and background knowledge I will pose the following questions:

1.) To what extent, if at all, do textbooks present the necessary presuppositions about the world and the b.k. that scientists use to give meaning to observations? Moreover, are these presuppositions and b.k. adequate for students to recognize reported observations and experiences as scientific evidence?

2.) What observations are reported by textbooks that scientists interpret as evidence? For example, a textbook may report that scientists observed the tracks of a dinosaur and were able to infer, from analyzing these tracks, that this particular dinosaur walked on two limbs only.

3.) Do textbooks discuss how scientists' evidence leads to the construction of a partially developed theory and eventually to a fully developed theory?

2.) Knowledge claims (k.c):

Scientists generate knowledge claims based on what counts as evidence. For example, scientists state that dinosaurs lived on earth 60 million years ago. This claim results from scientists finding such diverse evidence as dinosaur skeletal remains, radioactive dating of dinosaur fossils, existing background information on dinosaurs. Moreover, scientists ask questions, solve problems, and sometimes do experiments to generate evidence.

However, textbooks often state knowledge claims without adequately reporting how these claims were made. In fact textbooks often support a claim by only appealing to scientific authority. However, better reasons for support would have to include: pictures, tables and graphs, algorithms and exemplars, and finally experiments and activities. I shall argue that textbooks should give students "good reasons" to accept claims.

To understand how knowledge claims are connected to evidence and background knowledge, the textbook must show how these knowledge claims originate. In other words, I want to know if the textbook uses evidence to support these claims.

3.) Evidential Arguments:

Once scientists have established partially developed theories they search for supporting evidence to strengthen these theories. As new evidence becomes available, existing theories can be strengthened. Scientists of course must examine and evaluate all the scientific evidence connected with the theory. A theory therefore may be strengthened, abandoned or replaced, depending on how well the evidence supports it.

Evidence can then be examined and evaluated on how well it supports a theory. First, I will have to determine what scientific and pedagogical evidence is discussed in textbooks. An example of scientific evidence is Wegener's observation of the same flora and fauna fossils on different continents. Pedagogical evidence, on the other hand, consists of algorithms, exemplars, pictures, data and graphs which are designed by textbook writers to support laws, theories and principles. For example students may be asked to determine the offspring, using a Punnet square, of a crossing between a yellow short stemmed plant with a red tall stemmed plant. According to textbook writers this algorithm would support Mendel's hereditary law of the formation of dominant and recessive traits.

Next, I will have to determine the ability of textbooks to adequately support a theory. To evaluate this support I will examine textbooks to determine if the evidence provides strong or weak support for a theory? Strong evidential support can be illustrated in the following example. Textbooks may report scientists finding dinosaur bones which enabled them to construct the entire anatomical features of a dinosaur. The shape and size of the bones, plus the location, provides scientists with strong support for the theory that dinosaurs existed on the earth millions of years ago. Although this is strong evidence, it only provides scientists with part of the evidential argument for the existence of dinosaurs. For example, other supporting evidence such as radioactive carbon dating of bones and other geological fossil evidence are needed to provide stronger support for the dinosaur theory. On the other hand, weak evidential support can be illustrated in the following example. A textbook relates a story of how scientists were able to construct full scaled dinosaurs from bones found in the Badlands. However, I will argue that even though it is used with other evidence, anecdotal evidence provides only weak support for a theory.

All the appropriate scientific evidence connected with a theory must be included in the textbook and students must be given the opportunity to examine and evaluate all of this evidence. Appropriate evidence refers to evidence, presented in the textbook, which the students can understand.

Using these three levels of activity (background knowledge, knowledge claims and evidential arguments) for investigation of textbooks I will examine two science textbooks to determine if they provide adequate and appropriate scientific and pedagogical evidence to support a particular theory. For example, the textbook may report evidence for the continental drift but it may leave out the strongest scientific support (paleomagnetism) for the drift theory. Therefore, the textbook would not provide adequate scientific evidence to support the drift theory. Moreover, the textbook may also fail to report an important step in the development of the drift theory from a partially developed to a fully developed theory.

The main task of textbooks should be to report how scientists use questioning, problem solving, and experiments to construct evidence and develop scientists' evidential arguments to support their theories. I have already argued that evidence and evidential arguments arise from scientists' observations (which are based on their presuppositions about the world and their background knowledge), and their resultant interpretations of these observations. However, evidence is also connected with asking questions, solving problems and making knowledge claims.

I will examine the evidential arguments that are discussed in science textbooks to determine how they portray the questions that scientists ask, the problems they solve, the experiments they complete and the inferences they made from their experiments.

5.2 Textbook Analyses

I propose to examine the notion of evidence, following the outline above, as presented in the following textbooks:

a.) **FOCUS ON EARTH SCIENCE (1989)**

b.) GENERAL SCIENCE: A Voyage of Discovery (1986)

c.) **FOCUS ON LIFE SCIENCE (1989)**

d.) **GENERAL SCIENCE: A Voyage of Exploration (1986)**

The Focus on Earth Science and Life Science textbooks were chosen because they are a good representation of textbooks recommended for use by the Department of Education in Manitoba at the junior high school level. The General Science textbooks are widely used at the junior high level in Manitoba and recommended as a reference source by the Department of Education. The theory of continental drift and gene theory are included in these textbooks and they are part of the compulsory grade nine curriculum guide. Moreover, school teachers extensively use these textbooks as an important teaching resource. I will examine the continental drift theory in the following two textbooks: Focus on Earth Science and General Science: A voyage of discovery. The gene theory will be analyzed in the following two texts: Focus on Life Science and General Science: A voyage of exploration.

These two theories show, as part of general theory development, two approaches that are significantly different. The development of the continental drift theory, for example, depends heavily on Wegener's observations and less on the inferences he made from these observations. The development of the gene theory, on the other hand, relies more on Mendel's interpretations of the observations than on the observations only.

5.3 Analyses of the continental drift theory:

The first textbook I shall analyze involves Wegener's continental drift theory which is described in **General Science: A voyage of discovery.**

This textbook develops the theory of continental drift by first reporting an observation of how pieces of the African continent, as seen from outer space, seem to fit together. Next, the textbook asks the first major question: ***"Were they [the continents] once part of a single continent that broke up?"*** (General Science: A voyage to discovery p.200). However, surprisingly the textbook does not give any prior background knowledge on the continental drift theory. Clearly without more extensive background information, students will not be able to see this single observation as evidence for the continental drift theory. Indeed they will not be able to understand the question. The textbook seems to assume that students have a background knowledge about the continental drift theory and therefore will be able to "see" the evidence as well as understand the question.

To reinforce the theory that the present day continents were once a single large land mass, the textbook states that scientists and the astronaut-geologist, Harrison Schmitt accepted the idea that continents were in motion. The textbook does not discuss what kind of motion they are referring to and therefore students are left on their own to interpret the nature of motion. It seems that the only recourse for students is to accept what the textbook reports as the authority. Students do not have any other evidence to examine or evaluate to determine if continents can move or how continental drift occurred.

Following the observation (of continents from outer space) and the major question (which asked if the continents were originally one land mass), the textbook introduces Wegener's partially developed theory (p.d.theory) of continental drift. This theory involves making knowledge claims such as the textbook stating that;" ***About 160 million years ago, during the Jurassic Period, Pangaea began to break up. Like a jigsaw puzzle in reverse, the pieces of Pangaea slowly drifted apart.*** " and " ***By about 80 million years ago, there were two continents. Laurasia, the northern continent, was made up of North America, Europe and Asia."*** (p. 201). Unfortunately the only support given for these knowledge claims are pictures with captions indicating what the continents looked like 250 million years ago and what they will look like in the future. The textbook provides no other evidence to link these knowledge claims with the drift theory. Finally, the General Science textbook, at this point, does not provide students with any evidence that *Pangaea* broke-up during the Jurassic period. Once again, students are left with only unsupported knowledge claims and pictures to reinforce the theory of continental drift. Therefore, students do not have the opportunity to examine and evaluate evidence that led to the drift theory and eventually to these knowledge claims.

To introduce the evidence that Wegener used in his argument, the textbook asks the following major question: ***"How did Wegener get the idea that the continents of today had once been one huge continent?"*** (p. 202). I want to argue that this question could have been more appropriately asked at the introduction to the continental drift theory. It would have been a good opportunity for the textbook to introduce the presuppositions and background knowledge that led up to Wegener proposing his theory of drifting continents. The background knowledge would then have to consist of the pre-Wegenerian geological theories and arguments for continental movement. These pre-Wegenerian theories included the contracting earth theory and the solid earth theory, to explain the vertical movements of the continents.

Students would also have to be provided with background knowledge as to why Wegener questioned geologists' arguments. To accomplish this task students would have to be introduced to Wegener's presuppositions about the world and his background knowledge. Without these presuppositions and background knowledge it will be impossible for students to comprehend why and how Wegener proposed his theory in the first place. Students simply will not be able to recognize Wegener's observations and data as evidence and they won't be able to understand his evidential arguments in support of his drift theory.

The textbook would have to explain Wegener's presuppositions which include the principle of uniformitarianism and the principle of isostacy (refer to pages 19 and 20 for an explanation of these two principles). The textbook, however, seems to imply that students already have presuppositions about the world that include the principle of uniformitarianism. This is so because the textbook continually refers to evidence from paleontological records, paleoclimatic records and rock structures. For example, the textbook states that ***"by studying a series of sedimentary rocks, scientists learn much about the earth's past "*** (series refers to a group of sedimentary rocks laid down during a certain period of time in the earth's past) (p.203). However, the textbook does not make any direct reference nor attempts to explain the principle of uniformitarianism to students. Similarly, the textbook infers that students understand the principle of isostacy. It states: ***"The ice sheets began melting about 11,000 years ago. Since then, the lands have risen steadily, just as a ship rises in the water when its cargo is unloaded. "*** (p. 205) but again, no direct reference is made to the principle of isostacy nor is there any attempt, by the textbook, to explain how the principle works.

The textbook's indirect reference to the presuppositions about the world together with background knowledge are stated only **after** the textbook explains the evidence that Wegener used to propose and develop his drift theory. As previously mentioned in chapter three, evidence is dependent on scientists' presuppositions about the world and their background knowledge. Therefore, to help students follow and understand Wegener's theory, the textbook should have introduced Wegener's presuppositions and his background knowledge **prior** to reporting the evidence that he used to construct the continental drift theory.

I will now return to the question of how Wegener came upon the idea that the continents were once a huge land mass. The textbook introduces Wegener's evidence and evidential arguments that he used to support his theory of continental drift. This evidence, or what the textbook refers to as "clues," consists of:

1.) The shapes of the continents as observed by the astronaut-geologist and Wegener plus Wegener's ability to "fit" the continents together from old maps.

2.) The structure of the continents when Wegener compared the mountain ranges on two different continents and found them to be similar in structure and age. For example, he found that the structures of these ranges were formed by folding of similar types of rock 250 million years ago. The textbook, however, does not explain the concept of folding and how it is related to Wegener's theory and therefore students will not understand how it serves as evidence for his theory.

3.) Fossil remains in the series or layers of sedimentary rocks. This evidence consisted of fossil remains of flora and fauna which were similar in appearance and age but were found on different continents.

4.) Evidence of climatic changes from ice sheets to fern forests. The textbook makes this knowledge claim without explaining what the climatic changes were and why they are evidence for continental drift. Students will have difficulties understanding how climatic changes support the drift theory if they don't understand what these changes were and how they are related to the drift theory.

Referring to this evidence, the textbook states that: ***"All* [clues] *were strong arguments for drift. "*** (p.204). It is true that the evidence does present strong arguments for the continental drift theory. However, the textbook fails to include sufficient evidence and does not explain some important evidence that supported the drift theory. For example, the textbook does report and does not explain Wegener's data-analyses of the earth's topography and his mathematical calculations. These served as evidence and eventually led him to conclude that the earth consisted of two distinct levels: a continental layer and an abyssal sea layer. Knowledge such as the theory of a two level earth is essential to understanding why and how Wegener was able to propose his theory that the continents drifted apart. The textbook also fails to introduce Wegener's geophysical evidence, which included geodetic surveys indicating that the continents were slowly moving apart. Moreover, the textbook states that Wegener used climatic changes and folding as evidence, however, it does not explain what these changes were and how they served as evidence to support the continental drift theory.

The textbook then addresses the following major question (one that Wegener must have asked himself): ***" But how could continents drift on solid earth?"*** (p. 204). This question, however, would be more appropriately placed before the introduction to the drift theory instead of at the end of Wegener's evidential arguments. Even if this question had been appropriately placed prior to Wegener's formulation of the drift theory, students first have to understand the pre-Wegenerian theory. Geological theory (prior to Wegener) proposed that the earth was solid and made up of only one layer and was the accepted theory of almost all geologists. Moreover, geologists explained all vertical movements of the continents by the contraction of the earth as it cooled. The textbook does not explain to students that Wegener' background knowledge must have included knowledge of a solid earth theory. Students who are not provided with appropriate background knowledge will not be able to understand why Wegener would even ask such a question in the first place.

In response to the question of how the continents drifted on a solid earth, the textbook states the following knowledge claims, which are attributed to Wegener: ***"The granite blocks that make up the continents are afloat. They rest on an underlying layer of denser rock...Though this layer is solid, it can sometimes behave like a very slowly flowing liquid."*** (p. 204). The textbook does not attempt to explain how or why Wegener arrived at these claims. For students to understand these knowledge claims, the textbook would have to relate these claims to Wegener's presuppositions about the world (principle of isostacy) and his background knowledge. Without being acquainted with Wegener's presuppositions and background knowledge, students are left with only his knowledge claims without evidential backing. Therefore, students would have to accept these claims without being able to examine Wegener's evidence and evidential arguments that led to these claims.

The textbook then continues with Wegener's argument by stating that: ***"Wegener pointed out that most geologists already had accepted the idea that solid rocks can flow."*** (p.204). In supporting this claim the textbook states that the melting of the Ice Age 11,000 years ago allowed the land to rise up. However, the textbook fails to mention that geologists believed that the contracting earth theory accounted for movement of the continents millions of years ago. Without knowledge of the contracting earth theory, students are likely to believe that rocks can flow vertical solely on the basis of the explanation given by the textbook.

To continue with Wegener argument, the textbook introduces the next major question that Wegener would have had to ask himself: ***"If continents can move up and down...why can't they move side to side?"*** (p.205). Again the textbook does not explain why or how Wegener came to ask this question. To adequately answer this question, the textbook would have had to previously explain Wegener's presuppositions about the world so that students will be able to understand why he asked this question.

The textbook sums up Wegener's argument for continental drift by stating that many geologists rejected his theory that continents could drift apart. However, the textbook does not fully explain why most geologists rejected his drift theory except to say that Wegener could not explain the mechanism which caused drifting of the continents (that was a weak point in his theory). Moreover, geologists believed in the contracting earth theory which was contradicted by Wegener. They also believed that his theory was based on a catastrophic event. The textbook does, however, report that some scientists accepted his theory because it addressed many of their unanswered questions such as: ***why did the edges of some continents seem to fit together?*** and ***why did continents***

thousands of kilometers apart have geological features of similar makeup and structure? (p. 205)

Once the textbook has outlined Wegener's evidence and argument for continental drift, it states that geologists argued over his theory for thirty years. It does not explain, however, what these arguments were and why they persisted for so many years. Students are left to guess what happened during this period. More often than not, students are likely to believe that nothing important happened during this time period.

The textbook continues to introduce supporting evidence and arguments for the continental drift theory. This evidence came from Harry Hess's sea floor spreading theory in 1960 . The textbook introduces sea floor spreading by showing a world map (figure 7-20, p. 206) of major volcanic and earthquake sites. Then the textbook suggests that: ***if you were to place dots on a map where major volcano and earthquake sites exist on earth, the dots would outline the great mountain chain*** (p.206) Unfortunately, the textbook misses an opportunity to create an activity for students by asking them to place place dots on a map and then outline mountain chains. Such an activity would help to reinforce the theory of sea floor spreading as well as continental drifting.

More supporting evidence is reported when the textbook reports radioactive dating of rock samples as evidence for scientists to determine the age of the sea floor However, the textbook does not provide an explanation to students of what radioactive dating techniques are and how they can be used as evidence to support the drift theory. Therefore, students must accept the knowledge claim solely based on the authority of the textbook.

To reinforce the idea of radioactive dating as evidence, the textbook develops the following evidential argument: .. ***the ocean floors are nowhere older than about 200 million years old. Yet the earth itself is more than four billion years old.*** " (p. 207) and poses a major question that geologists must have asked themselves: " ***How can the planet be more than 20 times as old as the ocean floor that forms much of its surface?"*** (p. 207). "

The textbook then connects the sea floor spreading theory to the continental drift theory by returning to the original observation, that is, the separation of the pieces of the African continent. Moreover, the textbook makes the knowledge claim that sea floor spreading has been occurring since the break up of *Pangaea* . Unfortunately, the only evidence the textbook provides is the radioactive dating of the sea floor and the continents.

The General Science textbook is lacking two of the strongest pieces of evidence for the continental drift theory, namely the discovery of magnetism in continental and in sea floor rocks. The first piece of evidence was found when scientists compared the magnetism of the continental rock to the location of the continents. They inferred that polar wanderings of the continents had occurred. The second piece of evidence was the discovery of magnetic reversals in the undersea rocks which indicated to scientists that a new ocean floor was being continually formed and spreading out towards the continents. If these two essential pieces of evidence are omitted by the textbook then students will have inadequate evidence to support the drift theory or the sea floor spreading theory and they may or may not believe that these theories could occur depending on the adequacy of the evidence.

Final support for the drift theory is presented by the textbook using the **plate tectonics theory**. The textbook presents this theory by stating that it "pulls together" Wegener continental drift theory and Hess's sea floor spreading theory. However, the textbook reports the plate tectonics theory as knowledge claims without providing evidence to support it. Finally the textbook proposes two partially developed theories that may account for the force that drives the plates. The textbook states that both these theories have little evidence to support them.

The General Science textbook provides the reader with a progression from the initial theory to the fully developed theory. The continental drift theory does not have scientific evidence to explain how the continents moved and therefore it is a partially developed theory (Wegener provided scientific evidence which supported the notion that the continents did move). As more supporting evidence became available to explain how the continents moved, then scientists were able to construct a fully developed theory which was the plate tectonics theory.

The textbook also offers its own pedagogical evidence to convince students to believe in the continental drift theory and the plate tectonics theory. For example, the first activity is in the form of an algorithm (p. 211). It states that if two cities are moving towards each other at the rate of about 5 centimeters per year, then, in about 11 million years from now the two cities will be next to each other. The students are asked to calculate how many meters does each city have to travel before they meet. The support for continental drift comes from the students' ability to calculate the rate of horizontal drift. However, students would have to believe that a city can physically drift towards another city. Students may be able to do the algorithm but they may not believe that land can move. Algorithms must be used in connection with other evidence that supports the drift theory. For example, the textbook would also have to provide students with experiences such as the following activity.

This activity involves an experiment (p. 212) where students are asked to create a model to show continental drifting and the possible force for plate movements. This experiment is appropriate for showing students the possible mechanism for continental drift and how it works; i.e. heat source (light bulb) within the interior of the earth causes convection currents (syrup) which is the force that causes the continents (paraffin) to drift. Moreover, this model will be helpful in convincing students to believe in the evidence for the drift theory and the plate tectonics theory.

The General Science textbook should present scientific and pedagogical evidence to help students understand how science progresses and theory building occurs. Moreover, the textbook will have to explain scientists' presuppositions and background knowledge so that students have the opportunity of understanding what scientists "see" as evidence and how they construct their evidential arguments and theories. The textbook will also have to explain how it arrives at knowledge claims. Students do not have the opportunity to examine and evaluate the evidence if knowledge claims are only reported.

The second textbook involving the continental drift theory and plate tectonics, that I will analyze will be the **Focus on Earth Science**.

This textbook starts by first giving an introduction in the form of knowledge claims regarding the earth undergoing folding, tensional and compressional changes followed by this major question : ***What causes such*** [rock] ***movements?*** (Focus on Earth Science p. 433) The textbook assumes students know that the earth is undergoing these changes and they understand the concepts of folding, plus tensional and compressional changes. Without this background knowledge, students won't even be able to understand the question.

In the next section the textbook sets the stage for the introduction to the drift theory by giving students background knowledge which involves the beliefs of geologists prior to and during Wegener's time. The textbook reports that: ***In the past, people believed the positions of the continents and oceans have been constant. When accurate world maps were developed, people noted that the continents fit together like a puzzle. Until recently, the idea that the continents could move across the earth's surface was thought foolish.*** (p. 433) However, the textbook fails to explain why these people had these beliefs. Therefore, students are not provided with an adequate background knowledge so that they can understand Wegener's evidence to support the drift theory. Students have no other choice except to rely on those statements expounded by the textbook. For example, the textbook does not state that geologists, at Wegener's time, believed that the continents and oceans moved vertically but not horizontally. Moreover, the textbook fails to mention that scientists had viewed world maps but they had never connected the evidence of the continents fitting together, like a puzzle, with continental drift. If the textbook does not provide the background information to students, then students will not understand how Wegener was able to propose his drift theory.

In the next paragraph, the textbook reports Wegener's theory of continental drift with his detailed evidence and his evidential arguments. The evidence presented in the Focus on Science textbook is similar to the evidence that was reported in the General Science textbook. However, the evidence is more detailed in the Focus on Science textbook.

Next the textbook introduces Wegener's evidential arguments that were derived from his evidence and includes minor questions such as: ***could these beds (salt beds of Texas) have formed nearer to the equator and drifted north?*** (p. 434).

Following Wegener's evidential arguments, the textbook reports other scientific evidence that supported the continental drift theory. This evidence includes a detailed account of paleomagnetic evidence and an evidential argument which supports the drift theory. For example, the textbook reports that: ***From the direction of magnetism indicated by these rocks, scientists determined the pole position for European rocks of many different ages. When these data were plotted on a map, the location of the magnetic pole appeared to have migrated through time*** (p. 436). It is unclear from the text, what the concept of pole wandering is and how it supports the drift theory. The textbook fails to clearly explain scientists' evidence of magnetized rocks which indicated that the continents had drifted in relation to the poles. This evidence is supported by a picture (figure 20-4 p.436) of a polar wandering curve which is designed to show the apparent pole positions of the continents over time. However, I found it very it difficult to understand how this picture supports the concept of pole wandering and the theory of continental drift. If students cannot understand how polar wanderings occur, due to poor explanation of the evidence, then it is unlikely that they will be able to recognize how this evidence supports the continental drift theory.

The Focus on Earth Science textbook reports other scientific evidence to support the drift theory. This textbook follows a similar format to the General Science textbook in reporting the scientific evidence. Both textbooks first introduce knowledge claims about sea floor spreading and provide scientific evidence (the difference in age between the sea floor and the continents) to support scientists' claims. According to this textbook, the discrepancy of age between layers of the sea floor and the continents was the first "clue" (evidence) in support of the theory that the continents had drifted apart. Both textbooks present similar evidential arguments to explain how the sea floor spreading theory supports the Wegener's drift theory. The Focus on Earth Science textbook introduces the evidential argument by asking two major questions : 1.) ***Why is the ocean floor so young*** and, 2.) ***What is happening to the old seafloor?*** (p. 437). However, the textbook does not fully develop an evidential argument until after it explains the plate tectonics theory. The textbook states that: ***Sea floor spreading explains the bands of alternating directions of magnetism. It also explains the increasing age of the bands of lava away from the ridges*** (p. 441). The textbook should have explained the sea floor spreading theory when it introduced the above questions. This theory, if placed in the proper context, would have helped students understand how sea floor spreading supported the continental drift theory. Without adequately developing this argument, it will be difficult for students to see how the sea floor data serves as evidence in support of the drift theory.

The next supporting evidence reported by the Focus on Earth Science textbook was the discovery of alternating bands of magnetism in sea floor rock. The textbook builds an evidential argument by reporting that: ***scientists already knew that Earth's magnetic field had reversed repeatedly in the past. These bands reflected the magnetic reversals*** (p. 438). The textbook then asks the following minor question: ***But how were parallel bands of basalt deposited across the ocean basin floors?*** (p. 438). There is no effort in the textbook to explain how and why magnetic reversals had occurred. If students do not understand what alternating bands of magnetism are, then they will have difficulty understanding how the discovery of these bands serve as evidence in support of the continental drift theory.

The final supportive evidence for continental drift was provided when scientists proposed the **plate tectonics theory**. The Focus on Earth Science textbook makes a claim that ***data***

obtained from many sources led scientists to develop the theory of plate tectonics (p. 438). However, the textbook fails to explain what the data and the sources are, and how this data was evidence that led to the construction of the plate tectonics theory. The only evidence the textbook introduces to support the plate tectonics theory is when it states that: ***One of the most convincing pieces of evidence for plate tectonics is the age of the rocks within the Pacific Ocean basin*** (p. 449). The textbook states that when the ocean floor is created in the mid-ocean ridges and returned in trenches, the rate of plate movement should determine the maximum age of the rock in the plate. The textbook states that two "proofs" can be used to test this hypothesis. The first "proof" consists of knowing the average rate of ocean floor spreading per year followed by the maximum distance from the ridge to the trench in kilometers. Scientists can then calculate the rate of sea floor spreading and if the rate is constant, then no existing rock should be older than 250 million years old. The evidence to support this hypothesis is reported by the textbook that so far, scientists have not found any rock older than 200 million years old.

The second "proof", according to the textbook, would be a visit to Earth 100 million years from now to observe the positions of the continents. The argument consists of the following: if the plate tectonics theory is true in its predictions of continental movement, then it can be tested by comparing the locations of the continents today with the location of the continents 100 million years from now. One of the main problems, with this "proof" is that it cannot be verified until 100 million years into the future.

To convince students to accept the continental drift theory and the plate tectonics theory, the textbook introduces pedagogical evidence. First the textbook introduces an anecdotal story of a student trying to solve a problem by cutting out pieces of a map and trying to fit the pieces together to make one continent. Students are then asked to help solve the student's problem. This story will help students understand how Wegener was able to interpret his observations to construct evidence so that he could formulate his drift theory. However, this activity would be more worthwhile if students were asked to do this activity instead of just trying to solve a problem. It is important here for the textbook to state the relationship between the story and Wegener's use of evidence that helped him develop his drift theory.

The second evidential support provided by the textbook introduces pedagogical evidence in the form of experiments. In the first experiment (p. 440), the textbook tries to replicate, using a model, how blocks of the Earth's crust and the upper mantle move. Students are asked to simulate the bands of magnetic rock being exuded from mid-ocean ridges by using compasses (represents the change in magnetism of the rock), magnets (represents the magnetic poles) and folded paper (represents the extrusion of rock). This experiment helps reinforce the theory of sea floor spreading. However, students may have difficulties understanding the concept of magnetic reversals.

In the second experiment (p. 446), students are given a graph which simulates the magnetic field profile of the sea floor. Students are asked to measure the distance of the normal and reversed polarity over a time period from the mid-Atlantic ridge. Next, students are to record their data and calculate the rate of movement of the sea floor using the formula of, distance = rate x time. Students are then asked to interpret their collected data and explain what is happening in relation to the sea floor spreading. Due to the complexity of measuring, recording data, calculating scales, ratios and the rate of continental movement, students will probably have difficulties interpreting the collected data as evidence for sea floor spreading. In fact, students are likely to see this experiment as a mathematical problem to solve.

In the third experiment (p. 448) students are given data from a table which shows the depth and location of earthquakes along the coast of a continent. Students are then instructed to plot the depth versus the distance from the coast for each earthquake and then, from the data, they are asked to interpret the results in relation to what they know about plate boundaries. The experiment helps students to understand convergent plate boundaries but offers little support for plate tectonics. Students may become preoccupied with doing graph work and therefore they will miss the connection between the experiment and support for the plate tectonics theory.

The development of the notion of evidence for the continental drift theory and the plate tectonics theory is compared between the Focus on Science textbook and the General Science textbook in table 1.

NOTION OF EVIDENCE			SCIENCE TEXTBOOKS	
			Gen.Sc: A Voy. of Discovery	***Focus on Earth Science***
Presuppositions	principle of uniformitarianism		refers to both princ. but provides no expl. how they work	
	principle of isostacy		both these princ. are introduced at the end of the evid. argument	
			inferred but does not explain geologist's pre-Wegenerian paradigm	
Background Knowledge (b.k.)	geology, climatology , physics and mathematics		inferred but textbooks do not explain how background knowledge is connected to evidence	
Evol. of theories	partially-dev. theory	continental drift theo.	shows the development from cont drift theo to the plate tec.theory except textbook omits magnetism	does not show the connection from one theory to the next but includes detailed evid for c.d. th.
	to	sea floor spread theory		
	fully-developed theory	plate tectonics theory		
Knowledge claims (k.c.)			makes k. c. without support	more k.c. made but no support
Evidence	Wegener's evidence			
	outline of continents on old maps		adequately explained	ad. exp. & supported by an activ.
	data from earth's topography		not included in the textbook	not included
	measurement of earth's gravity		not included in the textbook	not included
	fossil records on different continents		adequately explained	detailed explanation
	geo. rock structures-faults and lithologies		faults are stated as a k.c. only	folding & comp. changes not expl.
	geodetic evidence		not included in the textbook	not included
	glacial deposits on different continents		stated but not explained	detailed explanation
	Other scientific evidence			
	paleomagnetism		not included in the textbook	included but not well explained
	magnetic reversals		not included in the textbook	included but not well explained
	sea floor spreading (s.f.s.) theory		explains s.f.s & its support c.d.t.	explains how s.f.s. supports c.d.t.
	radioactive dating		referred to as evid. but not expl.	referred to as evid. but not expl.
	plate tectonics (p.t.) theo-volcan.,earthquakes		consists of k.c. without supp evid	consists of k.c. without supp.evid
	Textbook (pedagogic) evidence			
	appeal to authority		uses scientists as authority to convince students of k.c.	
	pictures, data tables & graphs		uses pic. to support c. d. theory	uses pic.to supp.polar wandering
	algorithms and exemplars		uses algo. (calc.of moving cities as evid.) for c. d. th. & p.t.theory	
	experiments & activities		uses an exp. to show c.d.t. & p.t.t	includes 4 exp.to support c.d./p.t

Table 1 Comparison of the notion of evidence for continental drift in two science textbooks

5.4 Analysis of the gene theory:

I will next analyze the gene theory which is described in General Science: A voyage of exploration. This theory discusses the scientific evolution of heredity from Mendel's time to the discovery of the D.N.A. model.

The gene theory here is introduced by stating knowledge claims about the D.N.A. model. For example, the textbook states that: ***Hidden in the structure of the D.N.A. molecule are chemical instructions that shape every living thing***, and, ***scientists have unraveled the way in which the instructions in D.N.A. pass from one generation to the next*** (p. 407). Also,..***scientists have produced forms of life that have never before existed*** (p. 407) and ***research into D.N.A. has led to improved breeds of plants and animals and more efficient ways of producing certain medicines*** (p. 408). Students without any background knowledge about the D.N.A. model will have difficulties understanding these claims. Moreover, these knowledge claims are not supported by any evidence and evidential arguments and therefore students do not have the opportunity to examine and evaluate them. Students will have to accept the textbook's statements based solely on the reported knowledge claims. However, students, will accept the D.N.A. model because the textbook reports that scientists have "unraveled" and "changed" the instructions of the D.N.A. molecules and research has led to "improved breeding" and "efficient ways of producing certain medicines. " Here evidence clearly becomes an appeal to authority, i.e. statements made by scientists about the D.N.A. model.

Following the introduction to the D.N.A. model, the textbook states that in order to understand how D.N.A. was discovered, students would have to go back in history, to Mendel's time, and become acquainted with his experiments. To help students understand Mendelian genetics, the textbook provides certain background information. For example, reasons are given for selecting pea plants and a detailed explanation of the pollination process is presented. It is important for students to have this background knowledge, prior to Mendel's experiments. Students must understand how Mendel was able to construct his experiments and how he achieved his results. However, this background knowledge is not adequate to help students fully understand Mendelian genetics. The textbook must also introduce Mendel's presuppositions about the world as well as his background knowledge.

In the next section, the textbook describes Mendel's experiments in detail, including his results, which served as evidence. The textbook also discusses his scientific thinking which eventually led to the development of his laws and knowledge claims. For example, in the first experiment (p. 410), it is reported how Mendel crossed short plants and observed the results. Such observed results served as evidence and allowed Mendel to infer that these crossings produced true breeders. This acquired knowledge about true breeders led Mendel to ask the following major question: ***Did the seeds from tall pea plants give the same results*** ? (p. 410). To answer this question, Mendel conducted a second experiment (p. 410) by breeding tall plants. From the observed results, he inferred that these tall plants were not all true-breeders. Unfortunately, the textbook does not report, to students, that the results of Mendel's experiments will depend on what type of plant he originally had chosen. For example, if he had chosen tall true breeders then the observed results would have been all tall plants. Therefore the evidence would have indicated that tall plants were true breeders. However, the textbook reports that Mendel observed tall and short plants from his crossings. From this evidence, he then inferred that tall plants were not always true breeders. Students, reading this textbook, will probably ask this question: how can tall plants be true and non true breeders? Moreover, the textbook gives the impression that Mendel did some of his experiments haphazardly. In fact, he carefully controlled his experiments so that he could clearly recognize the results as evidence.

According to the textbook, results from his second experiment provided enough knowledge so that Mendel could ask this next major question: ***But what would happen, Mendel wondered, if he took pollen from a plant that produced only tall plants and dusted it into the pistil of a short plant*** ?(p. 410). This question led to the third experiment (p. 410) of crossing tall plants with short plants. In the first generation (F_1), he found that all the plants were tall plants. These results led Mendel to self-pollinate the F_1 plants in his fourth experiment (p. 411). The results of this experiment provided the evidence for Mendel to explain why some tall plants were not true breeders. Moreover, Mendel could make the important inference that plants had to contain "factors" for tallness and shortness.

The textbook reports that Mendel inferred from the evidence, that one trait was dominant while the other trait was recessive. To reinforce the concept of dominant and recessive, the textbook outlines two activities for students. In the first activity (p. 411) students are asked to observe hereditary traits of flowering plants of one species and then compare common and uncommon traits among these plants to determine which traits are dominant. I believe that this activity is based on the textbook's presuppositions that the common and uncommon traits are equated with a dominant and recessive traits. However, the question now arises for the reader: how can the textbook report that the observable results of common and uncommon traits are evidence for dominant and recessive traits? Moreover, students would have to know what traits were originally crossed to produce the observed results. The textbook gives students the impression that dominant/recessive traits can be easily determined. A more appropriate activity would be to ask students to grow and pollinate plants that clearly show dominant and recessive traits.

The second activity (p. 413) involves students raising guppies in three different tanks. The first and second tank contain only one noticeable trait , i.e. fancy-tailed guppies in tank one and plain-tailed guppies in the second tank. The third tank contains a mixture of these two traits. Students are asked to observe the offspring and answer the following questions:

-how are the offspring in each of the tanks similar to their parents?

-how are they different from their parents?

-what conclusions, if any can you make about dominant and recessive traits by observing the offspring in the third tank? (p.413)

If it possible to show that one trait is clearly dominant over another trait, then this activity is a good example to illustrate scientific evidence which supports dominant and recessive traits.

This second activity, involving the guppies, produces stronger supporting evidence than the activity involving common and uncommon traits because students are asked to do an activity which generates scientific evidence. However, this second activity will require more extensive preparation than the first activity.

Next, the textbook reports Mendel's fifth and the sixth experiments (p. 412) where he studied several plant traits to determine if mixture of traits occurred or if dominant and recessive traits still prevailed. The results were the same as the crossing from his second experiment, that is, dominant and recessive traits were expressed. I must express Mendel's results as he interpreted them and not in more contemporary terms such as genotypic and phenotypic results. To explain his results in contemporary terms would be to commit an anachronism.

I want to argue that the textbook should have explained, to students, that after Mendel interpreted his results of single traits, he could then predict what the observed distributions of multiple trait crossings would be, by using a mathematical formula of ratios. To validate these predictions, Mendel could then experimentally test to see if he obtained the same experimental results as he mathematically predicted. Students could then be given an activity where they are asked to predict the outcome of two or more crossings, using mathematical ratios. Next they could do an experiment which will support these predictions. The results of the experiment would then serve as scientific evidence in support of laws of heredity.

The textbook clearly outlines that as a result of his experiments, Mendel was able to formulate a hypothesis. It stated that there is a pair of factors for each trait and that these factors combined, one from the male parent and one from the female parent. Both factors can be carried in the first generation but only one will be expressed. Moreover, the pair of factors can separate, according to rules, and then rejoin in the next generation without mixing or blending.

The textbook also attempts to report a complete picture of the notion of evidence that allowed Mendel to formulate his laws. However, the textbook only provides a partial picture of evidence. To present a complete picture of Mendel's contribution to heredity, the textbook will have to include Mendel's presuppositions about the world and his background knowledge. Unfortunately, the textbook never refers to his presuppositions and his mathematical background knowledge which enabled him to formulate his laws. To adequately explain how Mendel was able to interpret his experiments in a new and novel way, the textbook would have to go beyond his experiments and his interpretations. For example, the textbook would have to report how Mendel was able to superimpose his methodology and statistical treatment on the results, so that he could make predictions of crossings which could be experimentally tested. Without presenting a complete picture of Mendel's evidence, students will be left with insufficient knowledge and therefore, they will have difficulties in understanding Mendel's full contributions to the field of heredity.

Not only does the textbook not give a complete picture of the evidence but it often attributes Mendel's scientific thinking to scientists' thinking today. For example, the textbook states that: ***Today, scientists use <u>symbols</u> to represent different forms of a trait*** (p. 411) but it fails to mention that Mendel's presuppositions and background knowledge enabled him to be the first person to describe hereditary traits in mathematical and symbolic form.

Other problems arise when the textbook inappropriately reports terms that are anachronistically out of context with Mendel's studies. For example, after stating Mendel's fourth experiment, the textbook reports that: ***Today these factors , or units of hereditary, are called <u>genes</u>*** (p. 411) and ***Today, this pair of factors is known as a <u>gene pair</u>. Unfortunately, Mendel was not aware of <u>chromosomes</u>*** and ***Mendel also did not know about the <u>process of meiosis</u>*** (p. 413). However, the textbook then continues to report Mendel's laws and experiments often using these terms even though it admits that Mendel was unaware of these terms. These terms were not associated with heredity until 1900 and 1909, some 35 to 44 years after Mendel first conducted his experiments. For example, the textbook reports that: ***the <u>chromosomes</u> have been segregated . This is known as the law of segregation*** (p. 414). ***Based on the results of these experiments, he*** [Mendel] ***formed the law of independent assortment. This law states that each <u>gene pair</u> is inherited independently of all***

other traits. The seven pairs of genes that Mendel studied separated independently because they were on different chromosomes (p. 414, 415). Unfortunately, students reading this textbook, will associate terms such as "gene", "gene pair" "chromosomes" and the "process of meiosis" with Mendel's work. To support these reports, the textbook uses evidence in the form of; a diagram of meiosis (fig. 18-7, p. 414), a diagram explaining segregation (using meiosis), (fig. 18-8, p. 414) and finally, a diagram of independent separation of different gene pairs on different chromosomes (figure 18-9, p. 415).

The textbook next introduces Mendel's law of probability by drawing an analogy between flipping a coin with the chance of landing heads up as compared to the chance of the sex cell receiving a dominant gene or a recessive gene from a hybrid parent. The flipping of a coin may be appropriate mathematical evidence to show the law of probability but, by itself, it is weak scientific evidence to support the notion of dominant and recessive traits in genetics To strengthen the evidential support for probability in genetics, the textbook must present scientific evidence, such as experiments, along with the mathematical support.

The textbook next states Mendel's laws of segregation, independent assortment and probability. However, the textbook does not explain how Mendel used his mathematical background to construct his laws of heredity. It would also have been more appropriate for the textbook to introduce the mathematical and scientific evidence for Mendel's laws at the same time as it reported his experiments. Students would probably understand how

Mendel was able to interpret the results of his experiments as evidential support that enabled him to formulate his laws.

The textbook sums up Mendel's work by stating that: ***Because of all the mathematics that was involved, the botanist did not really think Mendel's work was important*** (p. 417). However, the textbook does not state why the botanist (and other scientists) rejected Mendel's work on the bases of mathematics. It would have to explain how Mendel's presuppositions and background knowledge enabled him to interpret heredity in mathematical terms which was completely alien to the paradigm of geneticists in the late 19th century. Students will not understand what mathematics were involved in Mendel's work and how his mathematical background enabled Mendel to apply his reasoning to the results of his experiments.

The textbook next reports future experimental work and the development of theories which supported Mendelian heredity. For example, the textbook reports Correns's inferences from his experimental results that some traits are neither dominant nor recessive but instead are incomplete dominant. To support Correns's argument for incomplete dominance, the textbook outlines an activity for students (p. 418). Students are asked to solve a problem by tossing two marked coins one hundred times and recording the "genotype" for each toss. Each coin is marked with a ***R*** on one side and a ***W*** on the other side which symbolizes the red and white coloured flowers respectively. The results of this activity are supposed to serve as evidence for incomplete dominance. Again I want to argue that such results only serve as mathematical evidence for the law of probability and alone offer no scientific support for the concept of incomplete dominance. Students are unlikely to extrapolate the mathematical results from this activity to incomplete dominance in flowering plants. I believe that it would be more appropriate if students were asked to predict the ratios and then do an experiment such as growing plants in which the incomplete dominance trait can be observed.

The next supporting evidence reported by the textbook is Sutton's formulation of the chromosome theory in 1900. Sutton observed chromosomes undergoing meiosis and he inferred that ***the chromosomes carried the hereditary factors from one generation to the next.*** Also, ***he inferred that these factors accounted for the traits of an organism.*** (p. 418).

Other examples of evidence which the textbook reports include de Vries's experimental results which led to the discovery of mutations, and Morgan's experiments which resulted in evidence that supported his theory that certain chromosomes are sex linked. To support de Vries's knowledge claim that mutations are nature's way of producing varieties and new species, the textbook outlines an activity at the end of the chapter (p. 422). Students are asked to plant albino and normal corn seeds and then observe their growth rates. This activity supposedly shows the difference in growth between mutations and normal seeds. However, I would argue that it is not strong scientific evidence to show how mutations occur in genetics. To produce strong evidence, the textbook would have to present an experiment such as crossing fruit flies where mutations can be observed from normal crossings.

The textbook reports the above examples of experimental research in heredity and genetics without attributing their success to Mendel's original experimental results. Moreover the textbook fails to trace the evolution of the genetic theory from Mendelian heredity to the discovery of the D.N.A. model. Students will not understand that the development of the chromosome theory, the concepts of mutations and sex chromosomes plus the evolution of the D.N.A. model, all depended on Mendelian genetics for their inception. Unfortunately, students who read the textbook are likely to "see" scientific research and discoveries which are independent and disconnected from one another. I believe that textbooks must provide students with historical background information prior to introducing a new theory. For example, the textbook should have reported that by 1900 scientists had developed more precise instruments and histological staining techniques to study the cell. As a result, Sutton was able to connect Mendelian genetics to chromosomes and then propose his chromosome theory

The textbook goes on to report that: ***Between 1943 and 1952, scientists working with viruses and bacteria proved beyond a shadow of doubt that D.N.A. is the substance out of which genes are made*** (p. 420). However, there is no evidence provided to support the above knowledge claim that scientists working with viruses and bacteria proved the relationship between D.N.A. and genes. Students are left to guess what these workings were and how they proved beyond a shadow of doubt that genes are made up of D.N.A. Moreover, students are not given any evidence to examine or evaluate in support of this knowledge claim. To convince students that the above knowledge claim is true, the textbook, reports that: ***In fact, the complete genetic makeup of many forms of life is already on record in several enormous computers in the United States!*** (p. 420). Students will be convinced that D.N.A. is the basis of life because the textbook states that there are records on computers. The textbook's report then becomes the only authority. This knowledge claim, from the textbook, is the only evidence that students can examine and evaluate in support of these claims.

Finally it should be mentioned that the textbook uses algorithms to reinforce laws and theories in heredity. In the first example of an algorithm (p. 425), students are asked to determine the genotype of the F_1 generation from the crossing of two hybrids, using a Punnet square. The second example (p.425) involves calculating the number of tall stemmed plants from crossing one hundred, two hybrid plants. Both of these activities are based upon evidence to support the laws and theories of heredity. Students will probably learn how to do the algorithm but will not understand how the results serve as scientific evidence for heredity.

The final textbook that I will analyze, involving the gene theory, is the **Focus on Life Science** textbook. The textbook introduces the concept of heredity by asking students the following major questions: ***How can we explain variation and why are offspring like their parents? These are the questions of heredity*** (p. 313). From these questions the textbook introduces the work of Mendel by stating that: ***...Mendel became interested in the problem of how parents pass on characteristics to their offspring*** .(p.313). Prior to reporting Mendel's experiments, the textbook provides students with background knowledge of the definition for heredity, traits that he studied and the reasons why Mendel chose the pea plant for experimentation. Moreover, the textbook reports that Mendel was more successful in his studies of heredity than previous plant breeders because he worked with only one or two traits and he also worked with thousands of plants and kept detailed records of their ancestry. This background knowledge of these concepts and reasons are necessary to help students understand Mendel's experiments and the results from these experiments. However, the textbook fails to report some of the most important reasons for Mendel's success. For students to fully understand Mendel's contribution to heredity, the textbook will have to explain Mendel's presuppositions about the world and his background knowledge that enabled him to construct his experiments and to interpret the results of his experiments as evidence for laws of heredity. For example, Mendel applied his mathematical background to heredity in the form of symbols and mathematical ratios. Without knowledge and understanding of Mendel's presuppositions and background knowledge, students will have difficulties recognizing his experimental results as evidence.

The textbook continues by describing Mendel's experiments and his interpretations of these experiments. The textbook reports how Mendel experimented by crossing tall and short stemmed plants, observed the results and then with this new knowledge repeated the above procedures until he was able to formulate conclusions and hypotheses. From the evidence of crossing characters, Mendel inferred that a form of an inherited trait may be present without being visible. Moreover, the textbook reported that Mendel hypothesized that one form of a trait can mask another form. The textbook, then, explains dominant and recessive traits as they apply to Mendel's inferences and hypothesis. To support his arguments, the textbook uses figures showing self-pollination and the crossings between tall pea plants and short pea plants.

In the next section the textbook makes knowledge claims which state that for each trait there are ***at least two genes that control its inheritance-one from each parent*** (p.316). It continues by reporting that the genes from each parent pair up and if one gene is dominant, then it will mask the recessive gene. To support these claims, the textbook first shows a diagram (figure 15-3 p. 316) of a pair of chromosomes that come together during fertilization. Secondly, the textbook reports how a Punnett square is used to show all possible ways that genes combine during fertilization. To support these knowledge claims of the Punnet square, the textbook shows diagrams of Punnet squares which involves the crossing of pure tall (T) with pure short traits (t) (figure 15-4, p. 316) and the crossing between two hybrid tall pea plants (figure 15-5, p. 317). The textbook states that: ..***the offspring*** [from Mendel's second experiment] ***can be predicted with a Punnet square...***[and] ***In the second generation, we can predict three-fourths of the offspring will be tall*** (p. 317). Although the textbook reports that Mendel found this three-to-one ratio, it uses the Punnet square as mathematical evidence to explain the results of Mendel's experiments. The textbook does not state that Mendel had already used his mathematical skill to calculate these ratios long before the Punnet square was invented. Students will, therefore, be under the impression that Mendel used the Punnet square to express the genotypic crossing and that he was familiar with terms such as "gene" and "gene pair". Moreover, it does not explain to students Mendel's presuppositions that heredity could be expressed in mathematical terms and that his mathematical background knowledge enabled him to interpret the results of his experiments in the form of symbols, probabilities and mathematical predictions for crossings of multiple traits.

To support the ratios which were calculated by the Punnet square, the textbook outlines a problem in Investigation 15-1 (p. 318). Students are asked to place an equal number of red and white beans in one bag and the same proportions in a second bag. Next, students must predict the combinations of red to white beans using a Punnet square and write their predictions in a table. To test their predictions, students are asked to select one bean from each bag, repeat the trial one hundred times and write their results in a table. The results of the trials will then serve as evidence to support the predicted three-to-one ratio that was determined from the hybrid crossings using a Punnet square.

Instead of trying to verify the predicted three-to -one by using the law of probability or a Punnet square the students could have been asked to do a plant breeding experiment. The results would then be use to phenotypically show a three-to-one ratio. Then the textbook could introduce the mathematical evidence to support the scientific evidence from the experiment.

Another problem solving activity which the textbook employs to convince students to accept the law of probability involves tossing a coin and calculating the probability of heads or tails (p. 319). Students are provided with background knowledge of the probabilities of tossing two coins and having both turn up heads. They are then asked a series of questions that relate this background knowledge to heredity. Students are asked to use mathematical calculations to determine the probabilities of having four boys in one family. These calculations will serve as mathematical evidence for support of the law of probability and not scientific evidence for how human genetic crossings occur. Students are unlikely to understand the connection between mathematical evidence and scientific evidence.

To summarize Mendel's conclusions from his experiments, the textbook states his three major laws using terms such as genes, gametes, and chromosomes. However, even though Mendel constructed these laws from the experimental evidence, he was not familiar with these terms. Students will accept that Mendel developed these laws not only from the results of his experiments but also from knowledge of these terms. The textbook also should have incorporated these laws into the context when it reported each of Mendel's experiments.

Following Mendel's experiments and the results, the textbook introduces the concepts of incomplete dominance and multiple gene inheritance. The textbook uses detailed knowledge claims to explain these concepts. However, students are not provided with evidence to support these explanations. For example, the textbook claims that when short horned cattle are bred, and when Anadalusian chickens mate, incomplete dominance occurs in the offspring. However, most students do not have any background knowledge to understand these knowledge claims and how they apply to Mendelian genetics. Students will have to base their acceptance or non acceptance solely on these claims because they do not have any evidence to examine and to evaluate. Another example, reported by the textbook, states that several genes control the colour of the human eye. The textbook does not offer any evidence to support their claims of incomplete dominance and multiple gene inheritance of eye colour. Students must accept or not accept these claims without being able to examine and evaluate any evidence.

The textbook does provide support for the effects of multiple gene inheritance by outlining a mathematical problem solving activity (p. 321). Students are asked to measure the distance from their thumb to their little finger and then record the results on a table. Next, they are asked to graph hand distance to the number of students and then statistically interpret the results. This activity also involves presenting a series of questions which relates the statistical results to multiple gene inheritance. The textbook, in this activity, is trying to convince students that variation in hand length is evidence which supports the theory of multiple gene inheritance. However, the results of this activity are not necessarily evidence of multiple gene inheritance. Other variables could be responsible for the results such as; differences in heights and age of students, small sample sizes and cultural origins. This activity involves statistical analysis of the data and therefore students will likely focus on the mathematical calculations rather than on the experimental evidence. Again, students are unlikely to make the connection between the mathematical evidence and the scientific evidence.

In the next section, the textbook explains the concepts of mitosis and meiosis using diagrams, knowledge claims, and an investigation which compares the process of mitosis to meiosis. The textbook, however, does not connect the evolution of heredity from Mendelian genetics to the development of the chromosome theory which involves the processes of mitosis and meiosis. These processes are reported, by the textbook, as seemingly separate entities which are disconnected from Mendelian genetics. Moreover, the textbook fails to report the history of cytological research plus improved instrumentation, after Mendel's heredity experiments, which provided scientists with evidence that chromosomes existed and that they were the "carriers" of hereditary material. Students, reading the textbook, will not recognize that evidence from Mendelian genetics served as background information for the chromosome theory and that this theory, in turn, supported Mendelian genetics.

The textbook continues by stating knowledge claims and figures which describe genetic diseases, sex linked traits and D.N.A. model. Again the textbook reports the discovery of genetic diseases, sex linked traits and the D.N.A. model without connecting them to Mendelian genetics. For example, the textbook does not mention Morgan's experiments which led to the discovery of sex linked chromosomes and Watson and Crick's discovery of the D.N.A. model.

The development of the notion of evidence for the genetic theory (from Mendelian heredity to the D.N.A. model) is compared between the Focus in Science textbook and the General Science textbook in table 2.

NOTION	OF	EVIDENCE	SCIENCE	TEXTBOOKS
			Gen.Sc: A Voy. of Exploration	Focus on Life Science
Presuppositions	physical & mathematical laws		inferred but no direct reference to Mendel's presuppositions	
	govern nature		laws of independent assortment, probability & segregation are	
	organic forms are evolving		discussed but not connected to presuppositions	
Background				part. answers why Mendel was succ.
Knowledge (b.k.)	mathematics, physics, and biology		appropriate b.k. of pea plants and self- pollination	
			b.k. of chromo., genes, meiosis, mitosis,& D.N.A. inappropr. placed in Mendel's experiments	
			no evidential development of & D.N.A.model	
Evol. of theories	partially-developed (p.d.) theory to	heredity to	no supporting connections between theories	
	fully-developed theory	chromo. theory	ch. theory in form of k.c. only	ch. theory not mentioned
		& D.N.A. model	no evidential development of the D.N.A. model	
Knowledge claims (k. c.)			D.N.A. k.c. inappr. made in intro.	mitosis/meiosis expl.as k.c.
			except for Mendel's expts, other theories expressed as k.c. only	
Evidence	Mendel's evidence			
	experiments			
	1.) 2 characters-i.e. dominant/recessive characters		follows Mendel's initial observations, reasoning & experiments	
	2.) hybrid characters		reasoning is confusing	Punnett sq. used to expl. hybrid xing
	3.) more than two characters		inadequately explained	algo. used as evid to expl mult. genes
	math/stats tmt./ symbolism & pred. of characters		referred to but no evid. support	
	Other scientific evidence			
	chromo. theory,(Sutton), mutations (de Vries), & sex-linked chromo.& D.N.A.model (Watson & Crick)		reports observ. & expts. of scientists in the form of k.c.	scientists not reported & their discov. reported in form of k.c.only
	Textbook (pedagogic) evidence			
	appeal to authority		scientists & textbook reports as source of authority	
	pictures, charts, diagrams & data tables		supp. Mendel's expts, mitosis/meiosis, Punnet sq. & sex linked traits	
	algorithms & exemplars		problem solving to calculate genetic ratios & predict genetic results	
	experiments & activities		exp to supp.dom/rec & mutation	exp. to support prob.& dom/rec traits
			coin tossing to supp.law of prob	exp supp. multiple gene inheritance

Table 2 Notion of Evidence for the gene theory in two science textbooks

Chapter 6

Implications for Science Teaching

I have tried to argue that science textbooks generally present science as a dialogue of successes and offer an almost production-line image of science. Textbooks usually emphasize the products of science and seldom address the intellectual struggle that characterizes science. As a result, students perceive science as logical, that is always correct, and as a representation of the final view of the world. Therefore, students are usually left with no alternative except to memorize and accept or reject claims made by the textbook. Students are seldom given the opportunity to "see" how science changes over time.

To present a better image of science, textbooks must report how and why science changes over time. In fact, science textbook authors must present the central place of evidence in scientific inquiry if they want to help students understand the scientific enterprise. I recommend that science textbooks show how scientific theories develop using the notion of evidence as I have described in my thesis.

Students should also be given the opportunity to examine and evaluate evidence supporting each theory. It may then be possible for them to understand how and why the scientific enterprise works.

Science textbooks must address the central place of evidence in scientific inquiry if they are to be helpful to science teachers and to science students. To take advantage of such textbooks, science teachers.must already be familiar with the notion of evidence. However, from my personal experiences in formal science education, I found that like other science students, I rarely came in contact with the notion of evidence as described in my thesis. I agree with Gallagher (1991), and Brush (1989) that science teachers have very little formal education in the history and philosophy of science. Therefore, it is unlikely that these teachers will be familiar with the notion of evidence as presented in my thesis. As a result they will probably not teach science students how to adequately examine and evaluate evidence from science textbooks.

I agree with Gallagher that science teachers feel obligated to teach what is outlined in the curriculum guide. He found that the teachers he studied placed a strong emphasis on such things as memorization of science vocabulary and placed little emphasis on understanding the science knowledge. In fact, science teachers generally devoted very little time to discussing the nature of science with students except in Pearsonian terms (see Gallagher, 1991).

However, there are several possible ways to help teachers become familiar with the notion of evidence as central to the scientific enterprise. I recommend that science teachers use resource materials such as the Project Harvard Physics textbook, Scientific American, and documentaries such as *The Double Helix, Ascent of Man* and *The Voyage of Charles Darwin,* which deal with evidence and changes in theory development. I also recommend that science teachers study the notion of evidence from a historical perspective. Brush (1989), and Russell (1981), provide an insight into how the history of science contributes to the understanding of the scientific enterprise.

Another way teachers and students can become familiar with the central place of evidence is through constructing "science stories". Stinner (1990) suggests preservice science teachers construct "science stories" from the history of science. These teachers would make contact with the evidence that scientists used to develop theories and make knowledge claims. Preservice teachers, in turn, would help students develop their own "science stories". Students could then develop their own abilities to examine and evaluate evidence which supports a scientific theory.

Science textbooks will probably always play a role in science education. However, if science textbook authors play a significant role in helping students understand the scientific enterprise then they will report the place of evidence as it relates to scientific inquiry. In the future these authors then may change the role science textbooks play in science education.

References

Abell, S. (1989). The nature of science as portrayed to preservice elementary teachers via methods textbooks. In D.E.Herget, (Ed.), The history and philosophy of science in science teaching. (pp. 1-14), Tallahassee, Florida: Florida State University.

Allen, G. (1978). Thomas Hunt Morgan. New Jersey: Princeton.

Bishop, M., Lewis, P., & Sutherland, B. (1976). Focus on earth science. Columbus, Ohio: Charles E. Merrill.

Brush, S.G. (1989). History of science and science education. Interchange, 20(2), 60-70.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). 'An experiment is when you try it and see if it works': a study of grade 7 students' understanding of the construction of scientific knowledge. International Journal of Science Education, 11(special issue), 514-529.

Carlson, E. A. (1967) Gene theory: An historical approach. Belmont, California: Dickenson.

Collingwood, R.G. (1962). Metaphysics. Oxford: Clarendon Press.

Crick, F. (1954). The structure of hereditary material. Scientific American, 191(4), 54-62.

Denny, M. (1983). Children's perception of science: an analysis of infallibility in the coverage of evolution in 'textbooks' and some other teaching materials. Educational Studies, 9(2), 93-103.

Duschl, R.A. (1990). Restructuring science education. New York: Teacher's College, Columbia University.

Elliott, D.L. & Nagel, K.C. (1987). School science and the pursuit of knowledge. Science and Children, 24(8), 9-12.

Finley, F. N. (1983). Science processes. Journal of Research in Science Teaching, 20(1), 47-57.

Gallagher, J.J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. Science Education, 75(1), 121-133.

Hallam, A. (1976). Alfred Wegener and the hypothesis of continental drift. In readings from Scientific American: Continents adrift & continents aground. San Francisco, California: W.H.Freeman.

Hanson, N.R. (1961). Patterns of discovery. Great Britain: Cambridge University.

Heimler, C.H. (1989). Focus on life science. Columbus, Ohio: Merrill.

Hesser, D. & Leach, S. (1989). Focus on earth science. Columbus,Ohio: Merrill.

Huckabee, C. (1989). Influences on Mendel. The American Biology Teacher, 51(2), 47-57.

Hurd, D., Johnson, S., Matthias, G., McLaughlin, C., Synder, E., & Wright, J. (1986). General science: a voyage of discovery. Englewood Cliffs, New Jersey: Prentice-Hall.

Hurd, D., Johnson, S., Matthias, G., McLaughlin, C., Synder, E., & Wright, J. (1986). General science: a voyage of exploration. Englewood Cliffs, New Jersey: Prentice-Hall.

Hurley, P. (1968). The confirmation of continental drift. Scientific American, 218(4), 53-64.

Jacob, F. (1974). The Logic of life. New York: Pantheon Books

Kilbourn, B. (1970). Analyzing the basis for knowledge claims in science textbooks. From background paper no.6, The exploratory modes: Ontario Institute for Science Education.

Kilbourn, B. (1980). World views and science teaching. In H. Munby, G. Orpwood, & T. Russell (Eds.) Seeing curriculum in a new light. Essays from science education. Toronto, Ontario: Ontario Institute for Science Education.

Koestler, A. (1963). The sleepwalkers. New York: Universal Library Edition.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). The development of scientific thinking skills. California: Academic Press.

Kuhn, T. (1970). The structure of scientific revolutions (2nd ed.). Chicago: University of Chicago.

Lerner, L.S. & Bennetta, W. J. (1988). The treatment of theory in textbooks. The Science Teacher, 55(4), 37-41.

Mahadeva, M. N. (1989). From misinterpretations to myths. The Science Teacher, 56(4), 33-35.

Martin, B., Kass, H., & Brouwer, W. (1990). Authentic science: a diversity of meanings. Science Education, 74(5), 541-554

Marvin, U.B. (1973). Continental drift. Washington, D.C.: Smithsonian Institute.

Meyer, L. A., Crummey, L., Greer, E. A. (1988). Elementary science textbooks: their contents, text characteristics, and comprehensibility. Journal of Research in Science teaching, 25(6), 435-463.

Nadeau, R., & Desautels, J. (1984). Epistemology and the teaching of science (catalogue No. SS21-5/1984-6E). Ottawa, Ontario: Science Council of Canada.

O'Brien, D. (1990, May). Teaching for conceptual change: confronting children's experience. Phi Delta Kappan, 71(9), 680-685.

Orpwood, G., & Souque, J. (1984). Science education in Canadian schools. In volume 1, Introduction and curriculum analyses, Background study 52, Science Council of Canada, Hull, Quebec: Canadian government.

Peters, J. (1959). Classic papers in genetics. Englewood Cliffs, New Jersey: Prentice-Hall.

Renner, J.W., Abraham, M. R., Grzybowski, E.B., & Marek, E.A. Understandings and misunderstandings of eighth graders of four physics concepts found in textbooks. Journal of Research in Science Education, 27(1), 35-54.

Rogers, P.J. (1982). Epistemology and history in the teaching of school science. European Journal of Science Education, 4(1), 1-10.

Russell, T.L. (1981). What history of science, how much, and why? Science Education, 65(1), 51-64.

Scheffler, I. (1965). Conditions of knowledge. Glenview, Illinois: Scott, Foresman.

Science Council of Canada. (1984). Science for every student: educating Canadians for tomorrow's world. Report 36 (ISBN-o-662-11576-X), Hull, Quebec: Canadian government.

Souque, J. (1987). Science education and textbook science. Canadian Journal of Education, 12(1), 74-86.

Stent, G. (1972). Prematurity and uniqueness in science discovery. Scientific American, 227(6), 84-93.

Stinner, A. (1989). The teaching of physics and the context of inquiry: from Aristotle to Einstein. Science Education, 73(5), 591-605.

Stinner, A. (1990). Philosophy, thought experiments and large context problems in the secondary school physics course. Int. J. Sci. Educ.,12(3), 244-257.

Stinner, A. (1992). Science textbooks and science teaching:from logic to evidence. Science Education, 76(1), 1-16.

Stone, K. (1966). Evidence in science. Bristol, England: John Wright & Sons.

Strube, P. (1989). A content analysis of arguments and explanations presented to students in physical science textbooks: a model and an example. International Journal of Science Education, 11(2), 195-202.

Vachon, M.K. & Haney, R.E. (1983). Analysis of concepts in an eighth grade science textbook. School Science and Mathematics, 83(3), 236-245.

Webster's New Collegiate Dictionary, (1976). Springfield, Massachusetts: G.C. Merriam.

Williams, H. & Sinner, A. (unpublished). Science methods text.

Wilson, C. (1980). Starseekers. Milan: Italy.

Wilson, J. (1963). Continental drift. Scientific American, 20(4), 86-100.

Wood, T.L. & Wood, W.L. (1988). Assessing potential difficulties in comprehending fourth grade science textbooks. Science Education, 72(5), 561-574.