Science Fiction:

An Analysis of Science and Technology Secondary Cycle 1 Curriculum in Quebec

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ABSTRACT

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Quebec's Ministry of Education champions critical thinking as a goal across the secondary school curriculum. However, teachers are not trained in what critical thinking looks like, nor how to teach it. Furthermore, the current curriculum does not encourage it. This thesis seeks to address this problem in 3 parts. First, using theorists such as Freire, Hall, hooks, Gramsci, and Lewontin, I summarize a critical approach to science. I discuss how science can be used as a tool of social legitimization that upholds ideological hegemony through harmful discourse. I then demonstrate how this is happening in Quebec by performing a content analysis on two secondary school Science and Technology textbooks, using a modified Chiappetta, Fillman, and Sethna scheme. Finally, I offer alternative frameworks to science education by looking at a variety of approaches throughout the history of science education and feminist theory.

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Section 1 - Critical Theory in a Nutshell

Introduction

Science and Technology is generally assumed to be a field of objective facts and truth. Scientific ideology would have us believe that the phenomena of the world, and even the Universe, can be understood if only researchers have enough time and money to invest in discovering the facts that lay in wait. Man can conquer other planets, diseases can be cured, and increasingly microscopic chips will improve the quality of our lives. We are progressing, advancing, and developing. We look to science with great reverence, and consider "science as an institution, a set of methods, a set of people, a great body of knowledge... apart from the forces that rule our everyday lives and that govern the structure of our society. We think that science is objective. Science has brought us all kinds of good things" (Lewontin, 1991, p. 3). These ideals are constantly delivered to us through media (news, movies, radio, music, Internet), professionals (engineers, doctors, researchers), and our education system. They are deeply embedded within our culture of progress in Canada. It is these ideals that are perpetuated through our education system. But is it really possible for such a huge institution, funded and practiced by people, to be opinion-free and value neutral? With the help of several philosophers of science, education, and critical theory, I argue that science is not as objective as claimed to be, and point out why it is both dangerous and counter-educational to continue believing otherwise.

Science and Technology has been, and will increasingly continue to be, an important part of high school education in Quebec. I will discuss a few perspectives that can be considered when questioning how science is taught, and how it is used in society, in order to deepen our understanding of scientific texts and their producers. More specifically, I argue that Science and Technology, and how we teach it, is not value neutral. Quite to the contrary, I contend that the current Science and Technology curriculum upholds structures of inequality and acts as a tool of social legitimation.

In this section, I will begin by looking at the Ministry of Education (MELS) education goals for the Quebec high school Science and Technology curriculum. Since critical thinking is stated as a goal, it is important to consider what this means and how to teach it. I will outline key theorists who discuss the need for critical theory and how it can be applied to science education. In this regard, I begin with Paolo Freire's definition of critical theory and its importance to emancipatory education, supported by bell hooks. Then I will analyze *Biology as Ideology* (1991) where R.C. Lewontin argues that Science and Technology is not value neutral, and that much of the scientific method and the knowledge produced by it is a tool of social legitimation. To do this I will also make use of foundational ideas such as discourse and ideological hegemony. When talking about discourse, I rely on the definition by Stuart Hall, and when discussing ideological hegemony, I turn to Antonio Gramsci.

The Need for Critical Theory, Defined by MELS

The term “critical thinking” is often thrown around as a buzz word amongst educational scholars and cited as a goal in Quebec Ministry of Education (MELS) documents, but teachers have had little to no training to decipher its meaning, and few resources for implementing it in their classrooms. As a former Science and Technology teacher, my peers and I were often overwhelmed with the amount of material to cover but also the lack of resources or guidance in how exactly to teach critical theory in a science class. Although MELS states "exercising critical judgment" as the third competency for Secondary Cycle One and Two, there are few instances built into the Science and Technology curriculum that actually encourage this. Teachers are told that "in secondary school students learn to question their opinions and positions and analyze the values underlying them. They become aware of the influences to which they are exposed" (Ministère de l'Éducation, 2004, p. 41) and that teachers should guide students to "examine the issues involved, consider the facts, evaluate their accuracy and put them in perspective" (p. 40). However, the MELS-approved textbooks present Science and Technology as a collection of objective facts presented within a value neutral discipline, which is in direct contradiction with the claim that "there is no area of human activity in which people do not make judgments" (Ministère de l'Éducation, 2004, p. 40). The Quebec Education Program (QEP) considers "environmental awareness and consumer rights and responsibilities" as a broad area of learning and specifies that "in secondary school, the subject specific learning, together with collective activities, should provide students with many learning opportunities to take a proactive and critical approach to their surroundings and to examine their behavior as consumers" (2004, p. 26) but does little to help teachers tackle this educational endeavor. In Section 2 of my thesis I will look at textbooks in detail. Firstly, in Section 1, I will lay the groundwork for what is meant by critical theory, and then I will discuss how it can be applied within Science and Technology education.

The Need for Critical Theory, Defined by Freire and hooks

Paulo Freire was a Brazilian educator, theorist, and activist whose book *Pedagogy of the Oppressed* became a foundational text in critical pedagogy. He distinguishes between the oppressors and the oppressed and argued that the oppressed can play a role in their own liberation through an active participation in their education. This also means that oppressors need to be willing to question their methods and approaches, as “those who authentically commit themselves to the people must re-examine themselves constantly” (Freire, 1970, p. 60). Friere (1970) is also critical of the predominant “banking model” of education, where students are treated as empty vessels which teachers fill with information. He (1970) argues that education “transforms students into receiving objects. It attempts to control thinking and action, leads men and women to adjust to the world, and inhibits their creative power” (p. 77) which he considers unsurprising because “the more students work at storing the deposits entrusted to them, the less they develop the critical consciousness which would result from their intervention in the world as transformers of that world” (p. 73). Students are taught what and how teachers want to teach. Within systems of domination, the oppressed are taught to have a negative, powerless self-image and have lost, or never learned, the methods to critically respond to the dominating culture that has been forced on them. This creates what Freire (1970) called a culture of silence.

If Freire is right, this implies significant problems with our current education system, as the more students “accept the passive role imposed on them, the more they tend simply to adapt to the world as it is and to the fragmented view of reality deposited in them” (1970, p. 73). According to Freire (1970), the banking model we are teaching with minimizes and can even annihilate students' creativity and “serves the interest of the oppressors, who care neither to have the world revealed nor to see it transformed” (p. 73). Consequently, the need for analysis in education is immense and urgent if we aim to have a critically conscious student population, especially if this is a genuine goal of MELS.

The impact of critical practices can be significant, particularly in Science and

Technology. Looking back on my first year as a science teacher, I found that problematizing "facts" in science impacted the students even more than the questions raised in English and Ethics, Religion, and Culture (ERC). In English and ERC, students were used to a certain style of writing. By Secondary Cycle Two, they were already well acquainted with how to replicate the style of an essay, how to pick out the controversy in an issue, and how to mimic a critical standpoint. They wrote about viewpoints they did not necessarily hold, and sometimes they voiced opinions sarcastically to mock the style of humanities. However, writing a critical standpoint does not necessarily demonstrate having a critical standpoint. Freire argues that democratic and critical approaches to learning can only truly occur when they are genuinely being practiced. He points out that:

> [K]nowledge, above all others, can only be assimilated experientially. More often than not, we have attempted to transfer that knowledge to the people verbally, as if we could give lessons in democracy while regarding popular participation in the exercise of power as absurd and immoral. (Freire, 2013, p. 32)

This is not to say that the discussions and methods of English and ERC are not necessary. On the contrary, even the mere exposure to the academic practice of critical thinking is important.

However, in order for critical thinking to be an active process, it should be taught, encouraged, and exercised in all subjects so that students may see the relevance and applicability to their everyday lives. If we are to transform the way students learn, we cannot bracket the exercise of critical thinking to one specific subject or limit it to a unit of lessons specifically about critical thinking. As Freire points out, "responsibility cannot be acquired intellectually, but only through experience" (2013, p. 13). Instead of just talking about being critical, it is important to give students the opportunity to actually be critical and exercise that judgment. Accordingly, students are more likely to recognize and retain the need for critical thinking if it applies to several aspects of their existence in society and is more than just a writing style. A class in ERC can equip students with different theoretical frameworks and an English lesson can provide the students with the format and vocabulary with which to express themselves, but it is only through integration of critical thinking across all subjects that the goal of a critically conscious population can begin to be achieved. As Freire points out, "acquiring literacy does not involve memorizing sentences, words, or syllables – lifeless objects unconnected to an existential universe – but rather an attitude of creation and re-creation, a self-transformation producing a stance of intervention in one's context" (2013, p. 45). Critical thinking, then, is a dynamic process and a skill, not a memorized product. Science, which is assumed to be an objective field of facts, is the perfect fertile ground to unearth hidden discourses and critical perspectives.

As bell hooks (2000) reminds us, "everything we do in life is rooted in theory. Whether we consciously explore the reasons we have a particular perspective or take a particular action there is also an underlying system shaping thought and practice" (p. 19). Scientific theories have long been used to justify and uphold problematic power structures and inequality, or to sell products. In the age of rapid scientific and technological production, often called advancement or development, students need to be equipped with critical thinking abilities to filter the ideas and products that are being sold to them.

For example, it was merely 50 years ago that homosexuality was still considered a mental disorder that could be tested and treated by a variety of invasive tools. The *Diagnostic and Statistical Manual of Mental Disorders* (DSM), published by the American Psychiatric

Association as standard criteria for mental illness, only removed homosexuality in its second edition, published in 1968. Shock therapy, lobotomies, and social ostracization that LGBTQ people endured had very real and lasting effects on their lives and ability to participate in society. In hindsight, we can see that these medical procedures and scientific notions were heavily influenced by the values and beliefs of the ruling class of the time and now are understood to be untrue. Another example that I will detail in Section 3 of this thesis is that feminists had to fight for girls to have access to science education in the first place. At present, scientists are still publishing articles about the “natural” differences in ability and potential between the sexes, and races. Although there are perceived differences between men and women, or between races, we must start asking what underlies these perceptions of difference and how these narratives inform our world. Digging deeper, we must carefully consider whether we trust the institution of science to shape our understanding of the world by promising that there is a natural order just waiting to be discovered by specialists, and that the rapid growth of technology is for the betterment of humanity and without repercussion.

In order to analyze some of these questions, I will present R. C. Lewontin's (1991) critical approach from *Biology as Ideology*. However, I will first present the concepts of discourse and ideological hegemony, which are foundational to understanding Lewontin’s analysis.

The Concept of Discourse

Discourse, in anti-oppression theory, is “a group of statements which provide a language for talking about, or ways of representing, a particular kind of knowledge about a topic” (Hall, 1992, p. 291). When statements are made about a particular topic within a specific discourse, the topic is constructed by it. Discourse is not one particular statement but rather several statements in formation that work together and in relation to one another. Through its usage discourse is reproduced and influences all of our social practices. Discursive practice is the production of meaning. Therefore, since all social practices have meaning, all practices necessarily have a discursive aspect. Discourse is a way of talking, thinking, acting, and representing a particular topic. It has real social consequences, and is part of the circulation of power.

Discourse can be produced by many individuals from different institutions such as families, prisons, hospitals, and, as argued by Lewontin, science. This means that the person deploying the discourse is necessarily positioned within the discourse. Discourse is structured by positions that must be held in order to make sense of them. Discourses are not exclusive, they exist within other structures, and borrow meaning from other discourses as well. Previous, surrounding, and overarching discourses relate to the subject of whichever discourse is being referenced in the present place and time.

Another important aspect of discourse is that it has real social ramifications. Facts, even those of science, can be spoken about in different ways. Even scientific facts are spoken of within discourse, and these discourses can be made "true" or "real" because people believe in or act on them in ways that have consequences. In this instance, the discursive language has real effects on our beliefs and practices, which also means it is necessarily related to power. Those in power are those who produce knowledge.

For example, in "The West and the Rest" Hall (1992) points out that "the West" is a constructed concept, and it very much steeped in superiority. As an abstract concept, it allows speakers to condense a variety of people and cultures across vast territory to create a "standard model of comparison" and includes a list of "criteria of evaluation" against which other societies may be ranked (Hall, 1980). In turn, once we name that something is the West, we can also differentiate what is not the West, and that distinction affects inhabitants' lived realities. The importance of this example is not just to demonstrate that the concept of “the West” was created, but also, to point out that creating the West as an oversimplifying category has political power and affects how people live. It becomes significantly easier to appeal to Western nationalism and objectify, invade, and colonize “the Orient” or the rest of the world if we are looking at the situation as us vs them. According to Foucault (1980), when power enforces the “truth” of any set of statements, then such a discursive formation produces a “regime of truth” (p. 131). In critical theory it is vital to look at discursive practices in order to unpack these regimes of truth. It is with this definition of discourse that I consider how science is talked about and how scientific information gains importance in our society.

Gramsci's Ideological Hegemony

We can also view the importance of critical theory in Science and Technology education when we consider ideology and ideological hegemony. Ideology is a system of beliefs tied to the concept of power. Ideology is shared ideas and beliefs that serve the interests of the groups that create and maintain them. Ideological hegemony is the method through which ideology is controlled and used as a tool of control. Antonio Gramsci (1971) pioneered the concept of ideological hegemony by building on Karl Marx’s idea that the struggle between the ruling class and the working class is what propels society to move forward. There are two forms of control: domination through physical or direct coercion, and domination through ideological hegemony or indirect coercion. Explicit coercion is the direct force exercised by police, armed forces, and other institutions given legal power to exert physical force. Ideological hegemony, or indirect coercion, is comprised of ideological control which then leads to a certain level of consent. Gramsci went on to expand on how the ruling class dominated through ideological hegemony.

Ideology is a system of beliefs tied to the concept of power. Ideology is shared ideas and beliefs that serve the interests of the dominant groups that create and maintain them. Gramsci argues that ideological control is subtle but powerful, and perpetuates repressive structures. He contends that no institution can sustain itself primarily or solely through domination of state power and armed force, and that in order to remain stable, there must be support of the populace. Ideological hegemony are the ideas that are disseminated throughout the consciousness of society that serve the purpose of supporting the status quo in power relations.

> To the extent that this prevailing consciousness is internalized by the population it becomes part of what is generally called 'common sense' so that the philosophy, culture and morality of the ruling elite appears as the natural order of things. (Boggs, 1976, p. 39)

While domination occurs often through the overt threat of force, hegemony covertly convinces the oppressed that what the oppressor wants is in everybody's best interest.

Ideological hegemony is achieved when the dominated, oppressed classes in society accept the world view of the oppressive class as "common sense." When there is consensus that there is only one sensible way to view the world, then any alternative is easily marginalized and dismissed as nonsensical. However, it is important to specify that Gramsci considers hegemony, and the discourses that create it, to be largely unstable and temporary in nature. The ruling class, or, as Freire would call them, the oppressors, seek to keep their power by limiting thoughts and actions to serve their interests. At the same time, the dominated and oppressed still have agency and can fight for their own definitions of reality. This continuous struggle is ongoing and domination can only be achieved when the oppressed accept the ideological domination because they believe it serves their purposes or is common sense. Hegemony, unlike explicit coercion, convinces the oppressed that what the oppressors want is in everybody's best interest. For example, if we consider the West as better than the East due to technological advancement, progressive politics, and separation between church and state, it makes it easier to justify invading, occupying, and taking resources from the East in the name of education, or for their betterment. Likewise, if media convinces society that African Americans are more prone to violent and criminal behavior, then their incarceration or violence committed against them is in the interest of public safety. In both of these examples, domination is achieved through coercive powers of military and police, and is amplified or made permissible through ideological hegemony. If the populace does not accept military invasion or policing done by the government, then there will be revolt. It is far easier for the dominating class, which in these examples is represented by the government or the West, to convince military and police forces to exercise their power over “others” because it is for the good of all. Through discourse, ideological hegemony has the oppressed believe that what the oppressors want is in everybody's best interest.

Gramsci's idea of ideological hegemony can be used to expand on Lewontin's concept of science as ideology. The current methods of science instruction are meant to perpetuate an oppressive structure where students, and citizens at large, are not encouraged to think critically or engage with the facts. The idea that science is a body of facts that is value neutral has become part of our society's common sense, and it is through new critical approaches to education that we can grow out of this false consciousness. Discourse and ideological hegemony are the foundational bricks to my understanding of Lewontin's critical approach to Science and Technology that I will now proceed to detail.

R.C. Lewontin: Historical Context

Richard Charles Lewontin is an American-born evolutionary scientist and geneticist who became known in the academic world of biology during the 1960s and 1970s for contributing to the development of molecular population genetics and his use of electrophoresis when studying the evolutionary implications of enzyme polymorphism. His two research papers, co-authored with J.L. Hubby in 1966, are still considered to be classics in the field of evolutionary genetics. In 1972, he argued that genetic variation is greater within races than between them in his paper, "The Apportionment of Human Diversity," which is considered a landmark paper in human genetics and is still frequently cited in academic circles. His 1974 publication, "The Genetic Basis of Evolutionary Change" is still "required reading for aspiring population geneticists and philosophers of evolutionary biology" (Aronson, 1990).

However, during the 1990s, Lewontin pointed the microscope at a new subject: the role of science in society. He began to study how studies are done and the role such research processes play within society. In his 1991 book, *Biology as Ideology: the Doctrine of DNA*, Lewontin challenges the institution of science itself. He deconstructed the notion that science is an ivory tower of knowledge that discovers objective facts and posits that science, like any other institution, is socially molded and not as value neutral and objective as we are often taught to believe.

R.C. Lewontin: Science is Socially Influenced

Lewontin (1991) points out that scientists, like other members of society, are social beings immersed in a family, a state, and a productive structure (p. 3). Consequently, scientists see nature and perform their work through the lens of their social influences. Likewise, the science they study, practice, and create, is a social institution completely integrated into and influenced by the structure of all our other social institutions (Lewontin, 1991, p. 3). “Doing science” requires time and money much like other productive activities. Accordingly, it operates within the power structures of a world that heavily controls time and money. Since people earn their living by doing science, the practice and production of science operates under dominant social and economic structures.

R.C. Lewontin: Science Functions as Social Legitimation

Science, Lewontin argues, serves two functions: manipulation of the material world, and explanation, which often functions as legitimation of the social order. Institutions of social legitimation achieve ideological hegemony when they have convinced people that society is just and fair, or at very least, fair and inevitable (Lewontin, 1991, p. 6).

The first function of science is to manipulate the material world by producing a set of techniques, practices, and inventions by which new things are produced and the quality of our lives is changed (Lewontin, 1991, p. 4). It is an appeal to practical aspects of our lives and is most often cited when scientists are seeking funding. This function can often be seen in popular media when science is said to have made a new discovery. Lewontin (1991) points out that "we read repeatedly about how 'science has discovered' something, but more often than not those announcements are hedged with qualifiers. Biologists discover 'evidence for' genes that 'may one day' lead to 'a possible' cure for cancer" (p. 4).

The second function of science is much less well understood but is vital in the analysis of science education. Lewontin argues that science acts as a comprehensive apparatus of social legitimation. He says that even when scientists are "not actually changing the material mode of our existence, they are constantly explaining why things are the way they are" (1991, p. 4). He points out that "it is not at all clear that a correct understanding of how the world really works is basic to a successful manipulation of the world” (1991, p. 5) but these explanations serve another purpose: social legitimation. Regardless of the practical truth of scientific claims, the purpose of scientific explanations is often used as a way to justify why society is the way it is, and why individuals are the way they are.

Inequality of status, wealth, health, and power have been characteristic of every known society; therefore, there has always been a struggle between those who have and those who have not, between those with social power and those deprived of it (Lewontin, 1991, p. 6). Social institutions are created in part to appease these struggles. Science, Lewontin argues, is such an institution and is often used to convince people that there is an observable norm, and that injustices are par for the course. Institutions of social legitimation can be recognized by several features:

- The institution must “appear to derive from sources outside of ordinary human social struggle”
- “The ideas, pronouncements, rules, and results of the institution's activity must have a validity and a transcendent truth that goes beyond any possibility of human compromise or human error”

- and it must have a "mystical and veiled quality so that its innermost operation is not completely transparent and have esoteric language which needs to be explained to the ordinary person by those who are especially knowledgeable." (Lewontin, 1991, p. 7)

If an institution has these characteristics, it will likely be good at making the structure and inequality of society seem orderly, purposeful, and, most importantly, inevitable despite human effort.

Looking at the history of Europe, the most obvious example of an institution of social legitimation would be the Christian Church. If everything is ordained in a particular way by God, then inequality and injustice is simply a part of the natural order of things. Particularly if one is not poor, it is easier to accept poverty under the understanding that it is God's will than to admit that there is systematic oppression and power imbalance in society.

Science, Lewontin argues, replaces religion as the leading legitimating force in modern society. Better yet, science can cross borders because it claims to be apolitical and objective. Lewontin (1991) notes that "Science claims a method that is objective and nonpolitical, true for all time," (p. 8) which gives it strength as a legitimating force. Everybody can believe in science regardless of their political persuasion or location, whereas religion is limited to interpretation of religious leaders and their factions. Since science seems to be apolitical, it does not seem to have an agenda, ulterior motive, or to give citizens reason to be wary of its publications. Science gains its strength as a legitimating force because the scientific method is a practice and set of rules, not a person subject to political persuasions.

Furthermore, the results of scientific ventures are seen to be beyond human error. The scientific method prides itself on trying, trying, and trying the hypothesis again. Not only the methods and institutions of science are said to be above ordinary human relations, but of course, the product of science is claimed to be a kind of universal truth. The secrets of nature are unlocked. Once the truth about nature is revealed, one must accept the facts of life. When science speaks, let no dog bark. (Lewontin, 1991, p. 8). You cannot argue with science.

Finally, science also possesses Lewontin's third criteria for being an institution of social legitimation, which is its mystical and veiled appearance that needs deciphering by specialists. "Science speaks in mysterious words. No one except an expert can understand what scientists say and do, and we require the mediation of special people to explain the mysteries of nature because otherwise there is nothing but indecipherable formulas" (Lewontin, 1991, p. 9). Articles meant for the common person to understand explain using accessible language while the real nitty gritty details of research are footnoted or hyperlinked and interpreted by the presenter of the information. Scientific information is so mystical and specialized that it requires different types of scientists to interpret it. Lewontin (1991) points out that "one scientist [cannot] always understand the formulas of another" (p. 9). For example, a chemist might not understand a medical diagnosis, and a physicist would likely not understand a biologist's work.

Therefore, science as an institution has all of the characteristics Lewontin defines as being a powerful legitimating social force. It appears apolitical and claims objectivity, therefore it is derived from sources outside of the ordinary social struggles. Its test and re-test method said to prove facts goes beyond human compromise and error. Furthermore, its complicated language and formulas accessible only to highly educated practitioners of the field give it a mystical quality that needs to be predigested and interpreted for us common people. Therefore, we have several reasons to identify science as an agent of social legitimation, which is particularly dangerous to our education system as it furthers the power of ideological hegemony. This is highly problematic if educators are tasked with teaching critical thinking skills but are meanwhile furthering incomplete and inaccurate discourses about science and technology. If educators are teaching students that science is objective and value neutral, but as Freire (1970) and Lewontin (1991) have demonstrated it is not, then we are perpetuating the hegemonic power of the institution of science. In this instance, science teachers become another tool of oppression, and the education system continues to use the banking model.

Science Under the Influence of Social Values

In order to better understand the ability science has to influence and be influenced by social dimensions, let us take a look at some examples researched by Lewontin. It is important to bear in mind that Lewontin is primarily a scientist, and it was his work in the scientific field that lead him to question its discourse and critique its construction. In the following section I will discuss some of Lewontin's examples in an attempt to illuminate how some scientific theories that are considered common sense within the scientific community are in actuality quite uncertain and not at all value neutral.

Lewontin argues that, despite its claims to be above the influence of society, science, much like religion, is an extremely social institution that reflects and reinforces the dominant values of society. He points out that oftentimes, “the source in social experience of a scientific theory and the way in which that scientific theory is a direct translation of social experience are completely evident, even at a detailed level” (Lewontin, 1991, p. 9). In this section I will detail how social influences affected Darwinism, the problem of “part vs whole,” and the concept of cause and effect.

Darwinism

Lewontin's leading example of social influences on science is Darwin's theory of evolution by natural selection. Lewontin acknowledges that scientists consider it fact that organisms today evolved over billions of years from organisms unlike them that have now gone extinct. He also acknowledges that this process of evolution is the result of differential survivorship of different forms. In these areas, it is logical that scientists accept Darwinism to be true. However, Lewontin argues that Darwin's ways of *explaining* that process of differential survivorship and evolution are problematic.

Darwin himself was aware that his ideas about the struggle for existence and evolution came to him after he read late eighteenth century economist Thomas Malthus' work, “Essay on Population.” The text was an argument against the liberal English Poor Law, and favored a strict control of the poor so that they would not reproduce or create social unrest. Lewontin points out that Darwin's theory of evolution has a striking resemblance to Scottish economists' political and economic theories of early capitalism. Malthus' approaches to political economy were the context for Darwin's understanding of natural economy. This is the problem with explanations of science: like any other group of people, scientists are subject to the leading ideologies of their social class and culture. Scientists may be able to observe phenomena and show occurrences in the natural world, as demonstrated by Darwin pointing out the evolution of organisms, but how they explain such occurrences is worthy of examination. As Lewontin points out, scientists now consider Darwinism to be so true it is practically common sense. However, when reading Darwin closely, it becomes apparent that his understanding and explanation of natural phenomena gets inextricably tangled with social ideology which is troublesome considering the social context of the time was classist and against the breeding of the poor.

Lewontin remarks that social influences on science are generally fairly subtle. Scientists are, after all, part of a larger society, and if everybody holds similar views and values, then it is less obvious when those values influence explanations and outcomes of research. Lewontin refers to people's basic assumptions about the world they live in based on their cultural and social context. He points to “basic assumptions of which scientists themselves are usually not aware yet which have profound effect on the forms of explanations and which, in turn, serve to reinforce the social attitudes that gave rise to those assumptions in the first place” (1991, p. 10). In the case of Charles Darwin's research, it is highly problematic that a theory of natural selection grew out of, and was interpreted with the influence of, an economic theory meant to keep the marginalized from reproducing and organizing against their oppressors. So while natural selection and evolution is observable and predictable, we must be critical of the motivations for its research and the discourse surrounding the production of knowledge that followed.

Scientists do not operate in a social vacuum and to assume so limits the strength of their findings. If we can understand or at least have social influences signposted, we can get a more accurate understanding of the applicability of results. Whenever we ask a question, we must first clarify what are the question's premises. As we have seen in the case of Darwin's theories, social influences can greatly affect what research questions are asked and also how the results are interpreted. Another prime example of how social aspects influence the scientific process is the social understanding of the individual in the community, or a part vs the whole.

The Atomized Individual in the Reductionist View

One major example of social assumptions affecting scientific practice is the changing beliefs of how the individual relates to the community he lives in. Lewontin points out that Europeans in feudal times did not recognize the value of individuals in the way we do today. During these times, there was little if any importance placed on the individual within society. People's work, leisure activities, spending habits, and all around life were determined primarily by the social class they were born into. Accordingly, people were seen as parts of their social class, not as free agents with social mobility. This meant that individual people's life situations were seen as the result of their social arrangements, not the cause of them. Everybody had a predetermined role in society and individuals were not free to "work their way up" the economic hierarchy. Lewontin points out that:

> there was no freely moving competitive labor force where each person had the power to sell his or her labor power in a labor market. These relations made it quite impossible to develop the kind of productive capitalism that marks our own era, in which freedom for individuals to move from place to place, from task to task, from status to status, to confront each other sometimes as tenants, sometimes as producers and sometimes as consumers, is an absolutely necessity (1991, p. 11).

This social structure was largely reflected in their understanding of the developing field of natural sciences.

Early science of the Middle Ages and Renaissance approached the natural world as an indivisible whole. Nature could not be understood by dissecting its component parts because separating it would destroy what was essential to its whole being. Lewontin quotes Alexander Pope saying it was “like following life through creatures you dissect. You lose it in the moment you detect it” (Lewontin, 1991, p. 11). Here again we see the social influencing the scientific. Just as individuals were inextricably part of their social class cemented within the social and economic hierarchy, so too was the understanding of science.

This understanding of the individual within society, and consequently scientific understanding, changed with the development of industrial capitalism. In industrial capitalism, the individual is highlighted. He has now become the central focus of the economy, and he is independent and capable of transition and movement in the economic hierarchy. Lewontin (1991) notes that in the dawn of industrial capitalism, the individual was seen as:

> primary and independent, a kind of autonomous social atom that can move from place to place and role to role. Society is now thought to be the consequence, not the cause, of individual properties. It is individuals who make society. (p. 11)

This new recognition of the individual was also reflected in modern economics, which was grounded on the theory of consumer preference. Individuals could now compete, conquer, and replace each other. They became responsible for their economic success and social status, and possed power over their own bodies and labour.

This possessive individualism is also reflected in the reductionist view of nature (Lewontin, 1991, p. 12). Now, modern science approaches the whole by picking it apart to dissect its pieces. It is understood that if we want to understand the complex nature of something whole, we must look at it in parts, since the behaviour of the whole is entirely determined by the behaviour of the individual parts. The atomized approach in science reflects the individual consumer in economics, and, as we will see in the next section, it is problematic.

Causes and Effects

Another transformation that has occurred during the shift to modern science is a simplistic and problematic understanding of cause and effect. According to Darwin, organisms or parts are affected by the environment, the whole. Organisms were conceived as passive and the world surrounding them as active. This separation between the organism and its surroundings meant that each had its own governing laws and, most importantly, that the organisms could not affect the outside world. "Organisms find the world as it is, and they must either adapt or die. 'Nature – love it or leave it.' It is the natural analog of the old saying that you can't fight city hall" (Lewontin, 1991, p. 12). Lewontin argues that this is an incorrect view of the ongoing relationship between organisms and their environment. He explains that organisms modify and create the world they occupy based on their activities. This more nuanced understanding has great social repercussions as it necessarily means that humans can manipulate the world, though with differential access depending on social positioning and power.

What is being discussed here is the ideology of modern science. Modern biology treats individual units, whether they be atoms or people, as the source of the properties of their larger collections. This translates to viewing the world as disconnected individuals, and it means studying these as isolated parts. In terms of genetics, this idea means that living beings are entirely determined by their genes. In this view, we are merely puppets to our DNA or as Lewontin (1991) puts it:

> We are only their instruments, their temporary vehicles through which the self-replicating molecules that make us up either succeed or fail to spread through the world. In the words of Richard Dawkins, one of the leading proponents of this biological view, we are 'lumbering robots' whose genes 'created us body and mind.' (p. 13)

The next piece of the puzzle is not hard to see: if DNA determines genes and genes determine individuals, then by logical extension the bigger picture is that individuals determine their collectives. Lewontin uses the example of the ant colony. If we wish to comprehend the division of labor in an ant colony, we need to look to individual ants “because the behavior of the group is a consequence of the behavior of the individual organisms; that behavior is in turn determined by genes” (Lewontin, 1991, p. 13). In the case of humans, this means that the structure of our society is the result of individuals' behaviors. This means that “if we live in a competitive entrepreneurial society it is because, in this view, each one of us, as an individual, has a drive to be competitive and entrepreneurial” (Lewontin, 1991, p. 14). As we will see in the next section, this biologically deterministic view has profound (and oppressive) ideological consequences.

Scientific and Social “Revolutions”

The more the idea of individualism is perpetuated, the more the idea that unjust or unfair conditions are the fault of the particular properties of individuals and not due to systemic social arrangements. Here again we can see how science can act as an agent of social legitimation. When the idea of individualism is constantly being taught and reinforced through economics, science, and technology, it becomes significantly harder to recognize when social structures are oppressive, since the structures seem inevitable Cooperative social arrangements cannot work if individuals are naturally competitive. If our focus is constantly being put on the atomised, individual parts in society, it makes us less likely to point out problems with the whole or explore new possibilities regarding it. When the focus is put on parts, it is difficult to look at the whole, which perpetuates cycles of oppression by obscuring systems of privilege and oppression and placing the focus on the individual.

Lewontin states that the ideology of biological determinism has three central ideas: "that we differ in fundamental abilities because of innate differences, that those innate differences are biologically inherited, and that human nature guarantees the formation of a hierarchical society" (Lewontin, 1991, p. 23). Let us take a look throughout history to see how biological determinism has impacted scientists and their claims throughout different eras.

During the 17^{th} and 18^{th} centuries, Britain, France, and America revolutionized. The bourgeoisie claimed that they banished aristocratic privilege and replaced it with a new ideology of liberty and equality. The writers of the Declaration of Independence asserted that "all men are created equal; that they are endowed by their creator with certain unalienable rights; that among these are life, liberty, and the pursuit of happiness," (Jefferson, 1776) which Lewontin assumes to mean money and points out that "all men" was an exaggeration as it namely meant men of power, not women, who were only allowed the right to vote in Quebec in 1940, or slaves who were not "freed" until the middle of the 19^{th} century. Despite all the promises of the revolution and societies of free equals, the resulting societies featured "a great deal of inequality of wealth and power among individuals, between sexes, between races, between nations" (Lewontin, 1991,

p. 19).

In order to bridge the discrepancy of vast inequality in a society that claimed to be founded on equality, a new ideology had to be adopted. The alternative was to redefine the terms of equality. “Rather than equality of *result*, what has been meant is equality for *opportunity*” (Lewontin, 1991, p. 20). Lewontin uses the example of runners in a race. In pre-revolution society aristocrats start the race at the finish line while everybody else faces the barrier of running the actual race. However, after the revolution, it is understood that everybody starts at the same starting line with equal opportunity to run the race and succeed. Some people are faster runners than others, but there are no artificial barriers – just a natural selection. While pre-revolution society was said to have artificial barriers to equality, the new society blamed biological barriers—the losers of the race simply lacked the biological “right stuff.” This new definition does not rock the boat, as those who have power could keep it, while those who do not have power are lead to believe that place in society is “the result of their own innate deficiencies” (Lewontin, 1991, p. 20). Richard Herrnstein, a Harvard psychologist who is one of the most radical supporters of this view, has been quoted saying:

> The privileged classes of the past were probably not much superior biologically to the downtrodden which is why revolution had a fair chance of success. By removing artificial barriers between classes, society has to encourage the creation of biological barriers. When people can take their natural level in society, the upper classes will, by definition, have greater capacity than the lower. (as cited by Lewontin, 1991, p. 21)

This ideology, which is endorsed in less radical forms than Herrnstein’s by both the public at large and by scientists, has the effect of legitimating inequality. However, as Lewontin points out, there are problems with this discourse: to say opportunities are equal and the rest is all factors of natural selection is to blatantly ignore that children acquire social status from their parents (Lewontin, 1991, p. 22) and that lived conditions largely affect a child's academic success. Lewontin points out that roughly 60 per cent of blue collar workers have children who also end up being blue collar, while 70 per cent of white collar parents have children who remain in the white collar tax bracket. Meritocracy, then, cannot explain how parents pass their social power to their children.

The naturalistic response to this is to say that parents pass on the innate capacities, or in some cases, incapacities, to the next generation. But as Lewontin (1991) points out, “even the claim that the intrinsic ability to win success is inherited in the genes is not sufficient to justify an unequal society” because despite the argument that there should not be a “particular relationship between what one can accomplish and what social and psychic rewards are given” (p. 22) it is obviously not the case. A janitor does not get the same amount of social respect or monetary reward as a surgeon, even though both of them might perform their required tasks equally well.

Still, despite these problems, Lewontin notes that the biological theory of human nature and reductionist explanations of social structures remain popular amongst both scientists and the general public. The differences are in our genes. This ideology dictates that we all possess inborn similarities that guarantee that “differences in ability will be converted into differences in status, that society is naturally hierarchical, and that a society of equal reward and status is biologically impossible. We might pass laws requiring such equality, but the moment the vigilance of the state was relaxed we would return to 'doing what comes naturally'" (Lewontin, 1991, p. 23). This is a prime example of biological determinism.

Genes in Development

To understand the magnitude of the error that genetic determinism constitutes, Lewontin explains what occurs in developing organisms. He notes that although we are certainly influenced by genes, it would be incorrect to say we are wholly or even largely determined by them. In utero development is influenced by materials that have been inherited from parents' sperm and egg, but it is also affected by the specific temperatures, humidity levels, nutrition, smells, sights, and sounds (Lewontin, 1991, p. 26). Lewontin points out that even if we knew the complete molecular structure of every gene in an organism, it would be difficult to predict the exact configuration of the organism.

Another factor at play is developmental noise: the "random variation in growth and division of cells during development" (Lewontin, 1991, p. 27). Lewontin exemplifies this phenomena with the example of the bristles under the wing of a fruit fly, which is different in number on the left side than the right side without any average difference but still has the same genes on both sides. And since fruit flies are minuscule, both sides of the insect develop in the same conditions of temperature, humidity, and oxygen levels. Therefore the differences between the left and right side of the very same individual insect are caused by neither genetic nor environmental differences, but by developmental noise.

Neither Genetic Determinism nor Environmental Determinism: A Third Way

Lewontin argues that the ideological bias of modern biology is that "everything we are, our sickness and health, our poverty and our wealth, and the very structure of the society we live in are ultimately encoded in our DNA. We are, in Richard Dawkin's metaphor, lumbering robots created by our DNA" (Lewontin, 1991, p. 61). However, this reductionist view is deeply problematic, as it strips individuals, and consequently their societies, of their agency to manipulate and change the world we live in. The bourgeois emphasis on the individual permeates scientific understanding and creates a reductionist lens where "the individual makes society and society is nothing but the manifestation of the properties of individual human beings. Individual internal properties are the causes and the properties of the social whole are the effects of those causes" (Lewontin, 1991, p. 61). This cyclical understanding of cause and effect and individual agency means that internal forces define who we are, and by extension, also creates an external world of autonomous parts which we as individuals experience but do not – and cannot – influence.

When we look past the ideological biases of atomism and reductionism and look only at the relationships between organisms and their environment, we find a third way of understanding this relationship: a much more complex set of dynamic relationships that have a variety of consequences for social and political action.

Organisms do not just *experience* their environments; they *construct* them. Organisms create their own environments out of the physical and biological world with their own activities. Lewontin again uses his garden as an example. He points out that:

> The grass is certainly part of the environment of a phoebe that gathers dry grass to make a nest. But the stone around which the grass is growing means nothing to the phoebe. On the other hand, the stone is part of the environment of a thrush that

> may come along with a garden snail and break the shell of the snail against the stone. (Lewontin, 1991, p. 83)

This means that bits and pieces of the environment surrounding organisms are made relevant to organism by the organism's life activities. There are an infinite number of ways that parts of the world can be combined to make an environment, and we can only know what the environment of an organism is by observing that specific organism in its behaviors and activities within its specific environment.

But how do we live, and how do we want to live? How do we arrange our actions so that we can live the way we desire to? Lewontin (1991) points out that:

> Human beings do have a unique property not shared by other organisms. It is not the destructive property but the property that they can plan the changes that will occur in the world. They cannot stop the world from changing but they may be able with appropriate social organization to divert those changes in a more beneficial direction, and so, perhaps, even postpone their own extinction for a few thousand years. (p. 92)

Can Humans Organize Their Environments?

One might ask whether it is in the biological capacity of humans to organize the features of their environment in an attempt to prevent, or delay, extinction. Whether this is possible brings us back to the question of human nature and biological determinism. If organisms, or particularly human beings, have predetermined genes that make us individually more "entrepreneurial, selfish, aggressive, xenophobic, family oriented, driven towards dominance, self-interested in a way that precludes any real possibility for a radical reorganization of society" (Lewontin, 1991, p. 93) then human nature cannot be fought and all attempts would be futile unless technological solutions can be found which will permit us to continue our hard-wired bad behaviors. However, if "Kropotkin was right that human beings are biologically impelled towards cooperation and have been artificially held away from it historically, then…a reorganization might be possible" (Lewontin, 1991, p. 94). Lewontin believes that the ideological biases of science stop us from rethinking such a reorganization and drive us toward accepting the status quo as inevitable.

Conclusion

Quebec's Ministry of Education lists critical thinking as an educational goal across all high school subjects, including Science and Technology. However, teachers are ill equipped to teach critical thinking, as we are not trained in it nor are there resources to help. The first step to teach critical theory is to be critical of the curriculum ourselves.

In this section I detailed critical theorists in hopes of deepening our understanding of the institution of science and critical theory. I used Freire (1970) and hooks (2000) to argue for the necessity of critical thinking in education. I referred to Hall's (1992) definition of discourse and Gramsci's (1971) definition of ideological hegemony to explain how science education can act as a tool of oppression. I then expanded upon Lewontin's (1991) approach from *Biology as Ideology*, which argues that science is not politically neutral, but rather, serves as a method of social legitimation that allows us to accept deterministic understandings that perpetuate inequality in the world as inevitable. Lewontin also argues that due to the fact that science is intermeshed with the dominant ideology, a reasonable scepticism is necessary. At best, correlations are misunderstood and observable phenomena confirm basic assumptions and everything continues as status quo. At worst, the funders of research have a vested interest in seeing a particular result of their investment, and this affects how conclusions are read and knowledge that is produced. At either end of the spectrum, science is not in fact value neutral or objective, and the idea that it *is* value neutral and objective is highly problematic as it affects how we understand the world we live in. This is something students need to understand.

Now we have established that critical theory in science education is important because science has the potential to be, and is, an oppressive institution. With these characteristics of science in mind, I look quantitatively and qualitatively at Science and Technology textbooks in Section 2. I argue that current curriculum is severely lacking in the critical theory that the Ministry aims to foster, and features a questionable amount of discursive, non-participatory text that champions the reductionist view of science and the atomised view of the individual. In Section 3, I aim to bridge the gap between theory and practice by offering instructional recommendations. Using feminist theory, I propose ways we can teach Science and Technology without using it as a method of social legitimation.

Section 2 – Textbook Analysis

Introduction

Lewontin, as a biologist and an academic, makes the argument that science is influenced by, and can influence, its social environment. This perspective of science is easily seen in the basic, foundational levels of science education, specifically the Quebec high school curriculum. Furthermore, I argue that his perspective on science can easily but very significantly help science teachers incorporate critical thinking in their lessons. In this section, we look at high school textbooks to better understand the material being taught in Science and Technology. I use quantitative and qualitative analysis to dissect the two English Secondary Cycle One Science and Technology textbooks first using Chiappetta, Fillman, and Sethna's (1991) textbook analysis methods and then secondly using a categorization system I developed based on Lewontin's key characteristics of science. Having taught these courses before and being familiar with the texts, my aim is to show that these Ministry of Education approved and required textbooks perpetuate the idea of science as a monolith of truth, which is actually counter to critical thinking. I describe and define the types of information presented in these texts, create a link with Lewontin's explanation for why science is taught the way that it is, and propose how Lewontin's view of science can help us become better science teachers.

In the second part of this section, I analyze textbooks within the context of Lewontin's theory of science, presented in Section 1, in order to gain a better understanding of curriculum material and to lay the groundwork for offering some detailed suggestions for teachers in Section 3. In Section 1, we see Lewontin assert that science education not only manipulates the physical world, but is also used as a means of social legitimation. Lewontin argues that science is often presented as triumphal, as though the pure truths of life are just waiting to be discovered by objective scientists. This presentation of science as a pure practice that requires the interpretation of specialists makes science seem derived from sources outside of all social influences and forms the foundation for scientific findings to legitimatize social inequalities. By teaching science as a pure, triumphal and politically neutral subject, we do students a disservice in critical thinking.

In this section, I will start by detailing the methodology used for the analysis of the two English Secondary Cycle One texts, *Eureka* and *Connection.* I will then share the results and interpret them against Lewontin's perspective on science.

Methodology

Both English Secondary Cycle One textbooks, *Eureka* (2008) and *Connection* (2008), were analyzed. Both textbooks were analyzed in two phases. The first was a quantitative analysis using Chiappetta, Fillman, and Sethna's (1991) method for textbook analysis, and the second was one I designed based on Lewontin's primary characteristics and criticisms of science. When discussing the quantitative results of the two phases of research, I also added qualitative observations. I explain the analysis methodology separately for *Eureka* and *Connection* as they are structurally different textbooks with differing layouts and approaches to their respective topics. For example, *Eureka* is divided into units that are subdivided into categories, while *Connection* is divided into themes which are subdivided into parts, so while the same Chiappetta et al. and Lewontin categories were used in both textbooks' analysis, the selection of the chosen units and the terminology used to title each unit vary enough to warrant separate treatments so as to be unambiguous.

Chiappetta et al.'s Mode of Analysis

As we saw in Section 1, “Critical Theory in a Nutshell,” lessons in science are not just about the observable phenomena in the natural world. Scientific practice is steeped in social values, and research results can be used to justify and perpetuate unbalanced social power. Science teachers rely heavily on textbooks to shape the information and activities in their course. In Quebec, teachers are required to use one of the approved textbooks and evaluate according to a standard curriculum. If we are trying to understand science education, then, a good starting point to see what is happening in classrooms is to analyze the textbooks.

Chiappetta, Fillman, and Sethna (1991) recognize that teachers often center their courses around textbooks, and that textbooks heavily influence youngster's perceptions. For example, they point out that a textbook that highlights mainly facts and concepts teaches students that science is a “neatly organized body of information” while a textbook that poses a lot of questions and is composed mainly of hands-on activities is more likely to teach science as investigative (p. 3). Accordingly, Chiappetta et al. developed a textbook analysis scheme to answer the question “What message does a given textbook convey to the reader about science?” (p. 3).

They based their analysis scheme on Garcia's (1985) work in scientific literacy, which suggests that text can be organized under four categories: (1) basic science knowledge, (2) investigative skills of science, (3) science as a way of thinking, and (4) the interaction of science, technology, and society. From there, Chiappetta et al. detailed these themes and included subcategories for specificity. They are as follows, with coding numbers in brackets following the description:

1. The knowledge of science. [Facts about science]

Check this category if the intent of the text is to present, discuss, or ask the student to recall information, facts, concepts, principles, laws, theories, etc. This type of text reflects the transmission of scientific or subject matter knowledge, in which the student receives information. It presents information to be learned by the reader.

Textbook material in this category:

a. Presents facts, concepts, principles and laws. (11)

b. Asks students to recall knowledge or information. (12)

2. The investigative nature of science. [Science tasks]

Check this category if the intent of the text is to stimulate thinking and doing by asking the student to "find out." This type of text reflects the active aspect of inquiry and learning, which involves the student in the methods and processes of science such as observing, measuring, classifying, inferring, recording data, making calculations, experimenting, etc. The instruction can include paper and pencil as well as hands-on activities.

Textbook material in this category:

a. Requires the student to answer a question through the use of materials. (21)

b. Requires the student to answer a question through the use of charts, tables, etc. (22)

c. Requires the student to make a calculation. (23)

d. Requires the student to reason out an answer. (24)

e. Engages student in a thought experiment or activity. (25)

f. Get information from the Internet. (26)

However, if a question simply asks for recall of information or is immediately answered in the text, check Category 1.

3. Science as a way of thinking.

Check this category if the intent of the text is to illustrate how science in general or a scientist in particular went about discovering ideas. This aspect of the nature of science represents thinking, reasoning, and reflection where the student is told how the scientific enterprise operates. This type of text also presents the scientific method(s) and problem solving.

Textbook material in this category:

a. Describes how a scientist experimented. (31)

b. Shows the historical development of an idea. (32)

c. Emphasizes the empirical nature and objectivity of science. (33)

e. Shows how science proceeds by inductive and deductive reasoning. [Code as this only if it presents this information as a deliberate discussion of this issue.] (35)

g. Discusses evidence and proof. [Code as this only if it presents this information as a deliberate discussion of this issue.] (36)

h. Presents the scientific method(s) and problem solving steps. [Code as this only if it presents this information as a deliberate discussion of this issue.] (37)

4. Interaction of science. technology and society.

Check this category if the intent of the text is to illustrate the effect or impact of science on society. This aspect of scientific literacy pertains to the application of science and how technology helps or hinders humankind. It involves social issues and careers. Nevertheless, in the presentation of this type of material, the student receives information and generally does not have to find out.

Textbook material in this category:

a. Describes the usefulness of science and technology on society. (41)

b. Stresses the negative effects of science and technology on society. (42)

c. Discusses social issues related to science or technology. (43)

d. Brings out careers and jobs in scientific and technological fields. (44)

Modifications to Chiappetta et al.'s Scheme

I followed the modification to Chiappetta et al. used in Waddington and Imbriglio's (2011) analysis of high school Science and Technology textbooks. They added:

5. Instructions

Check this category if text give instructions to students how to use the textbook or complete a basic task.

Textbook material in this category:

a. “instructs the students to perform an activity or a step in a lab task” (2011, p. 161).

b. lists equipment (52)

c goals (53)

d. textbook mapping (54)

I added 5.b, c, and d, as I noticed many units of text did not fall under the 4 previous categories. “Goals” includes motivational words, learning objectives, or desired outcomes from the activities provided in the text. They often explicitly state the importance of a particular activity, or how it relates to the rest of the unit. For example, the text “This Way to the Finish Line” at the bottom of *Eureka* page 159 tells students “During your classmates' presentations, record the information that you find most relevant. It will be useful to you when you present the energy system that you chose for your dream home.” “Textbook mapping” entails text that gives directions to other parts of the textbook. This type of text includes footnotes, citations, and references that directs readers to refer to other texts within the book. For example, this reference in the sidebar of page 92:

How to Apply the Design Process SKILLS HANDBOOK, p. 436-438

Technical Diagrams ENCYCLOPEDIA, p. 386- 388

Material and Equipment ENCYCLOPEDIA, p. 391 (*Eureka*, 2008)

The goal of coding with Chiappetta et al.'s method is to gain an overview of the types of information in the textbooks, and to preview what sections of the text most commonly feature or lack critical approaches. For example, is the majority of the textbook made up of instructions for experiments, historical anecdotes, or modern-day examples science in action? Of those categories of information, are critical approaches present or lacking more in a particular type of text or in a specific topic? The analysis chart featured the following categories:

Textbook page number	Chiappetta Category	Has potential to feature critical perspective (y/n)	Features critical perspective (y/n)	Comments

While doing the analysis, I added a qualitative commentary column. I made a space for comments because Chiappetta et al.'s analysis could sort the type of information but not necessarily its content or the ideological implications behind the choice or presentation of content. This distinction is key in the discussion of critical content. Since I wish to investigate not just what is being presented but *how* and *why* it's being presented, reading past the surface level is important. For example, *Eureka* "Chapter 2: Keeping up with Our Energy Needs," Activity 4 features a standalone paragraph: "Quebec is a world leader in hydroelectricity, and the history of hydroelectric development in our province is fascinating. Do some research to learn more about it" (2008, p. 162). Although the first sentence is a fact that can be coded as

Chiappetta et al. code 11, the overall relevance of the paragraph to the rest of the unit is neutral at best. If anything, the paragraph starts with a fact but then continues onto a narrative that serves to hook the reader using grandiose terminology about hydroelectricity. It is worth noting that this text example is also featured in the side margin of the main text, in a different colored bubble, making it stand out like an endorsement ad in a magazine. It is not part of, nor does it lead to, a bigger, more clearly structured activity. In this case, a comment would be written, questioning the inclusion of this material in the text.

Eureka analysis

Analysis Phase 1 - Chiappetta et al. Textbook Analysis Applied to Randomly Selected Samples from the Textbook

Eureka is divided into 4 Units, followed by 4 Worlds, and then 12 Topics. Firstly, the number of sections in the textbook were counted. “Section” in the case of *Eureka* was any group of pages delineated by a chapter title. Introductory pages were included in the count of the first chapter of each section so they could be included in the analysis while not being treated as a chapter on their own. More precisely, this meant that introductions were included in the analysis but not counted as their own chapters.

Secondly, the sections were selected. Using the random number generator found at www.random.org:

Eureka Part 1: The Units—I selected a random chapter from each “Unit”.

Eureka Part 2: Encyclopedia—I selected a random section from each “World”.

Eureka Part 3: Skills Handbook—I selected a random “Topic” from the 3 topics

Using this method, a sample chapter/section is taken of every Unit and World. Since Part 3: Skills Handbook has fewer pages per Topic than the chapters of Part 1 and the sections of Part 2, only 1 of 3 Topics is sampled. The length of 3 topics is roughly the same length as the average chapter and section. In order to determine the sample size, I used the following procedure based on Waddington & Imbriglio's (2011) adaptation of Chiappetta et al.:

> "Because the number of pages devoted to each topic was considerably different for each textbook—some containing a small number of pages, others a large number—a sliding scale was used to calculate the number of pages to be analyzed. Some sections had as few as four pages. In this case, each unit of analysis on each page was included in the study.
>
> 80% of the pages were included in the analysis when sections were 5–9 pages,
> 40% of the pages were included with sections containing 10–14 pages,
> 25% of the pages were included with sections containing 15–19 pages,
> 20% of the pages were included with sections containing 20–24 pages, and
> 15% of the pages were included with sections containing 25 or more pages.
>
> The page numbers in each section were randomly generated. These pages were then photocopied, and the individual units of analysis were numbered on each page. A unit of analysis is defined as: complete paragraphs; figures, pictures, and tables with captions; marginal comments and definitions; questions in and at the end of the chapter; and each complete step of a laboratory or hands-on activity" (Waddington & Imbriglio, 2011)

Once chapters have been determined and number of pages calculated, I generated which pages to sample at random. If the pages that were selected did not have enough codeable items, I generated another random page. If the same page was randomly selected twice, I selected another at random. Any numbers that resulted in fractions equal or greater than a half were rounded up.

Analysis Phase 2 – Lewontin Analysis

Following the application of Chiappetta et al.'s analysis on randomized units of text, I looked at the results and selected a section of the textbook to analyze in its entirety using the Lewontin categories. These categories were designed by taking the key elements of science according to Lewontin's philosophy of science, discussed in Section 1 of this thesis. They are as follows, with coding numbers in brackets following the description:

1. Science as highly classified information.

Text in this category demonstrates science as:

a. Beyond human influence. (11)
b. Mystical in nature. (12)
c. Requiring specialists' interpretation. (13)

2. Science as a "pure" practice.

Text in this category is an example of science being practiced without mention of the negative ramification of scientific practice on the social and environmental environments they are performed in. (21)

3. Science as facts.

Text in this category is an example of science as:

a. Triumphal. (31)
b. Excessively varnished. (32)

c. Overly optimistic, nature as a collection of truths just waiting to be uncovered. (33)

4. Science as social legitimation.

Text in this category upholds hegemonic power structures and the status quo by:

a. Presenting science in any time period as predominantly performed by white men. (41)

b. Assuming a heteronormative, middle-class student body. (42)

Results - *Eureka*

Eureka is designed as a Secondary Cycle One student textbook for the Science and Technology course. In the textbook foreword message, Editorial Director Tran Khanh-Thanh invites the reader to “the fascinating world of science and technology” and promises that “the units in this textbook were specifically written to accompany you on your amazing discoveries of the plant and animal kingdoms” (2008, p. iii). In case an early teenager was doubting the need for Science and Technology in their lives, Khanh-Thanh points out that “when you study science, you are learning about the whole history of scientific thought and procedure” and that “you will want to know more and find answers” and boasts that “you will see the world from a whole new perspective” (2008, p. iii). Khanh-Thanh addresses the audience as a “budding scientist” and says “you will observe nature and tell other people about your observations in detail [including] relationships that you have discovered to explain various phenomena [verified] through experimentation” (2008, p. iii). He assures the budding scientists that they “will develop reasoning skills” and “be able to explain how you tested opinions and ideas, and what effect scientific and technological activities have on society” just as “scientists do when they conduct research" (2008, p. iii). The editorial director also aims to let students "study science by taking part of it" and assures that at very least, *Eureka* "will help deepen your understanding of the amazing world that you share with other living creatures around you" (2008, p. iii).

Based on the terminology used in the foreword alone, we should not find it surprising that Lewontin criticizes textbooks for presenting Science and Technology as triumphal, excessively varnished or overly optimistic as a collection of truths just waiting to be discovered. I look further into the textbook to get a better understanding of the material itself.

In order to understand the make-up of the text, I analyzed the textbook using Chiappetta et al.'s (1991) textbook, "Categories for Analyzing Science Textbooks," as previously discussed in the methodology. Following Chiappetta et al.'s methodology, I randomly selected a designated percentage of pages of each *Eureka* unit. From there, each section of text on the page, including paragraphs, side notes, and captioned images, was sorted into one of five categories:

1. The knowledge of science,
2. The investigative nature of science,
3. Science as a way of thinking,
4. Interaction of science, technology and society,
5. Instructions.

(see methodology for further detail). Each of these categories was subdivided for specificity. The results of the analysis are summarized in the following table:

Table 1

Analysis of random sample of Eureka *according to categories/subcategories of Chiappetta et al.*

Category/Subcategory description	Subcategory Code	Frequency
The knowledge of science		
Presents facts, concepts, principles and laws	11	212
Asks students to recall knowledge or information	12	22
The Investigative Nature of Science		
Requires the student to answer a question through the use of materials	21	3
Requires the student to answer a question through the use of charts, tables, etc	22	4
Requires the student to make a calculation	23	1
Requires the student to reason out an answer	24	12
Engages student in a thought experiment or activity	25	48
Get information from the Internet	26	0
Science as a way of thinking		
Describes how a scientist experimented	31	0
Shows the historical development of an idea	32	3
Emphasizes the empirical nature and objectivity of science	33	0
Shows how science proceeds by inductive and deductive reasoning	35	0
Discusses evidence and proof	36	0
Presents the scientific method and problem solving steps	37	4
Interaction of science, technology and society		
Describes the usefulness of science technology on society	41	7
Stresses the negative effects of science and technology on society	42	0
Discusses social issues related to science or technology	43	0
Brings out the careers and jobs in scientific and technological fields	44	4
Instructions		
Instructs the student to perform an activity or a step in a lab task	51	31
Lists equipment	52	3

Science Fiction		45
Textbook goals	53	13
Textbook mapping	54	23

Table 2

Analysis of random sample of Eureka *according to Chiappetta et al. (results sorted by frequency)*

Rank	Subcategory (code)	Frequency
1	Presents facts, concepts, principles and laws (11)	212
2	Engages student in a thought experiment or activity (25)	48
3	Instructs the student to perform an activity or a step in a lab task (51)	31
4	Textbook mapping (54)	23
5	Asks students to recall knowledge or information (12)	22
6	Textbook goals (53)	13
7	Requires the student to reason out an answer (24)	12
8	Describes the usefulness of science technology on society (41)	7
9	Requires the student to answer a question through the use of charts, tables, etc (22)	4
9	Presents the scientific method and problem solving steps (37)	4
9	Brings out the careers and jobs in scientific and technological fields (44)	4
10	Requires the student to answer a question through the use of materials (21)	3
10	Shows the historical development of an idea (32)	3
10	Lists equipment (52)	3
11	Requires the student to make a calculation (23)	1
12	Get information from the Internet (26)	0
12	Describes how a scientist experimented (31)	0
12	Emphasizes the empirical nature and objectivity of science (33)	0
12	Shows how science proceeds by inductive and deductive reasoning (35)	0
12	Discusses evidence and proof (36)	0
12	Stresses the negative effects of science and technology on society (42)	0
12	Discusses social issues related to science or technology (43)	0

This data indicates that, of the sampling of the entire textbook, 54.36% of the text presented facts, concepts, principles or laws. The second most frequent type of text fell into the category of “engages student in a thought experiment or activity;” however, this was a mere 12.3% of the sampled text. The third most frequent type of information instructs the student to perform an activity or a step in a lab task, counting for 7.95% of text. Thus, we see that the predominant type of text presents science as an orderly body of knowledge, while less than a quarter is hands on activity.

In the foreword, Khanh-Thanh promises that “when you study science, you are learning about the whole history of scientific thought and procedure” and that “you will want to know more and find answers” and boasts that “you will see the world from a whole new perspective” (2008, p. iii). This is a dubious statement in light of the fact that a mere 1% of text presents the scientific method and problem solving steps, and an even more marginal 0.77% shows the historical development of an idea. 1% is the same amount of text that brings out careers in the scientific and technological fields, and less than the 1.79% of text that describes the usefulness of Science and Technology on society.

If the goal of *Eureka* is only to invite teenagers to the “fascinating world of science and technology” then it might seem reasonable that over half of the text presents facts, concepts, principles, or laws. The same could be said of the editorial team's writing “to accompany you on your amazing discoveries of the plant and animal kingdoms” (2008, p. iii). But we must consider the large amount of information that falls into this Chiappetta et al. category with the critical lens of Lewontin: we need to look past the presence of facts and concepts and ask how and why certain facts are presented over others. As Lewontin (1991) points out in *A Story in Textbooks*,

> information in a textbook has the authority of science. In an important sense, it *is* science because science consists not simply of a collection of true facts about the world, but is the body of assertions and theories about the world made by people who are called scientists. In consists, in large part, of what scientists say about the world whatever the true state of the world might be. (p. 77)

This can certainly be seen in the facts and concepts raised in *Eureka*.

For example, in Unit 3, “Warning! Major Changes Ahead,” an interesting story is told about climate change. Although the chapter presents many facts about climate change, the angle it takes on those facts is questionable. “Chapter 1: The Permanence of Change” discusses the disappearances of species over time, but as a “natural phenomenon” and goes on to assure readers that “the living things populating Earth today would likely never have existed if not for the disappearance of an earlier species” (2008, p. 100), which makes extinction sound necessary and even fruitful. However, nowhere in the text does it point to the fact that the human race can go extinct, largely because of our over consumption of the earth's resources. There is also no mention to humans contributions to the extinction of other species.

The text continues to ignore the social effects of science throughout the unit. The first activity discusses Darwin's finches in terms of natural selection and evolution, then goes on to discuss aurochs, wild oxen, that were tamed by humans and have since gone extinct. Since *Eureka's* foreword promises that the text “will help deepen your understanding of the amazing world that you share with other living creatures around you” (2008, p. iii), it would seem reasonable that this unit would lead to the discussion of extinction and the permanent changes that the unit title warned us about. However, the text does nothing to mourn the extinction of the animal, nor does it warn us about the disadvantages of causing animals to go extinct. Instead, it goes on to boast that cows today produce much more milk, a "spectacular result" of selective reproduction done by humans over the course of thousands of years (2008, p. 102). This presentation of concepts would lead us to believe that it does not matter that aurochs no longer exist because they have been replaced by cattle whose production for human consumption has been maximized by the use of the science and technology of selective breeding.

The next activity, "What Changes Can Occur in my Environment," begins by asking "What kind of experiment would enable you to verify the effect of an environmental factor on a living organism?" (2008, p. 103). The next phrase asks, "Could you use animals to study how they react to an environmental change?" but immediately answers that "[t]wo factors make us reject this kind of experiment," citing first the length of time to raise animals and then, that it is unethical to subject animals to difficult conditions (2008, p. 103). Instead, it proposes students research the ways environmental changes can affect the cultivation of wheat and barley.

The problem with this approach is three fold. Firstly, the format, phrasing, and directions do not encourage students to actively participate in science. The textbook poses two questions, then immediately provides a negative answer. Rather than having guiding questions about different types of experimental possibilities or allowing students to come up with their own ideas about experiments on animals, the text provides a firm answer. Deadending the exploration of questions with firm and inarguable statements teaches students that science is a predetermined body of knowledge, not a participatory activity or a method of discovery.

Secondly, it further removes the process of science from every day people by ignoring the role humans play in their environment. By looking at environmental changes, it does not acknowledge human involvement, thereby ridding us of our responsibility. If aurochs have "gone extinct" after being tamed by humans, we should be asking how humans affect living organisms, not just the "natural" environment, which is largely defined as soil and weather in this chapter. Secondly, the subject of environmental change becomes even more removed from human responsibility if the activity is designed to discuss cultivated plants instead of animals. It avoids the reality of human consumption to discuss the extinction of aurochs and then go on to discuss how plants have been historically affected by weather conditions.

Thirdly, the activity asks, "Could you use animals to study how they react to an environmental change?" and goes on to argue that it would be "unethical to subject animals to difficult conditions in order to see how an environmental change affected them" (2008, p. 103). As a solution, it proposes instead that students research past weather patterns that have affected plant production. Since the previous page discusses the extinction of aurochs after humans tamed them for production, it would seem more relevant to answer the activity's question by looking into the history of human consumption of cattle instead of the historical weather differences of wheat and barley. Furthermore, this would be a good teaching opportunity to discuss the ethics of animal testing, which does occur in science despite the textbook's admonition, or the ethics of breeding livestock for consumption in the first place. Neither of these possibilities are raised, and the opportunity to practice critical thinking is lost.

Another activity within the chapter discusses how students can make a greenhouse to control the weather conditions that might affect the production of wheat and barley. This activity involves completing a technical drawing and building a greenhouse that meets several specifications but is most notably, 15cm tall and 100cm2 and built from recycled materials if possible. Here again we see busywork that is unclear in educational value. Students are asked to perform a task that has no clear bearing on the scientific principle they are studying. Firstly, recycled material that could build a greenhouse 15cm tall is unlikely to withstand actual conditions outside. Secondly, a greenhouse of 100cm2 would not be big enough to grow wheat or barley. Thirdly, there are very few, if any, damaging weather conditions that occur in the classroom. These three steps significantly distance this activity from educational purpose.

Together, these three activities implicitly suggest to students two problematic ideas: one, that humans do not affect their environments or the extinction of species and two, that humans can use science and technology to prevent the problems that result from their actions. Although there is some truth in the second idea, this is a troubling narrative with which to approach environmental change because we are a society that over consumes and wastefully produces. When we teach students that everything can be fixed, then we are overlooking the problem: how to not break things in the first place. This is an example of how the ideological hegemony of science as an institution is created. If we believe that science can fix everything, then we can avoid having to question or change our behaviors that cause the problems in the first place.

Furthermore, although the unit is called “Warning! Major Changes Ahead!,” it never once addresses the issue of climate change by name, nor does it present the reader with anything that actually constitutes a warning. To the contrary, the bulk of concepts are followed up with how Science and Technology can or will make things better. The activities introducing the unit on environmental changes are unfortunately the norm and not the exception in the textbook. They are exemplary of Lewontin's argument that the modern vision of science presents it as triumphal, presented as bringing only beneficial social ramifications.

Further to this point, it is worth noting that of the 390 items randomly selected from the entirety of *Eureka*, not a single one stressed the negative effects of Science and Technology on society (Chiappetta code 42) nor did any item discuss social issues related to Science and Technology (Chiappetta code 43). It did, however, have 7 examples that described the usefulness of Science and Technology in society (Chiappetta code 41) and 4 examples that highlighted careers and jobs in scientific and technological fields (Chiappetta code 44).These four subcategories made up the Chiappetta coding category 4 “Interaction of science, technology, and society.” This means that only 2.82% of the overall text explicitly highlighted the positive interaction of science and technology and society, or brought out its usefulness. This category was vastly outweighed by the number of items that pertained to the knowledge of science (60%), the investigative nature of science (17.44%), science as a way of thinking (1.8%), and instructions (17.95%).

This may seem as though the narrative of *Eureka* is not triumphal, as relatively little time is dedicated to explicitly talking about the benefits of science. However, as seen by the previously stated examples, facts and instructions for activities are not value neutral. The facts about the auroch were more about science's ability to breed more productive cattle, and the instructions to perform activities were exercises in fixing problems in which the social roots were ignored. Overall, the presentation of Science and Technology in *Eureka* is implicitly triumphal. Even though less than 3% of the text directly mentions the positive interactions of Science and Technology and society, we can see from the examples above that the text implicitly treats Science and Technology as a solid and organized collection of truths and not a socially driven activity. The 60% majority of the text pertaining to the knowledge of science does not allow students to investigate, participate, or question science. Rather, it implicitly teaches students that experiments have predetermined results and that science is an established body of knowledge to memorize. This implicit lesson contributes to both the strength and the inaccessibility of scientific discourse and perpetuates its ideological hegemony. At best, students perform unrelated activities and memorize seemingly arbitrarily related concepts, and at worst students become alienated from subject that seems to have no bearing on their lives. In both cases, science remains a rigid set of facts and concepts that require specialists to interpret.

To investigate in greater detail, I did a chapter analysis using the Lewontin method to categorize every unit of information in a chapter of *Eureka.* The random sampling across the entire textbook gave me a good look at the layout of the book and an overview of the types of information it presented in different units, but the chapter analysis was to provide an in depth look at the flow of a chapter as it would be taught in a classroom, and to make sure no type of activity or narrative would be missed. The following Table 3 summarize the results. For the raw data records or the explanation of the categories, please see attached.

Table 3

Lewontin analysis of whole chapter of Eureka

Page	Lewontin categories	Comments
87	43, 31, 43	
88		Table of contents
89	21, 33	
90	13	
91	21	Abstract experiment
92	44	
93		Abstract news headline

94		Abstract experiment
95	44	
96	44, 31	Chapter summary
97		Abstract experiment

Table 4

Chiappetta et al. analysis by code frequency of whole chapter of Eureka

Rank	Subcategory (code)	Frequency
1	Presents facts, concepts, principles and laws (11)	34
2	Goals (53)	32
3	Instructs the student to perform an activity or a step in a lab task (51)	20
4	Engages student in a thought experiment or activity (25)	17
5	Textbook mapping (54)	9
6	Requires the student to reason out an answer (24)	7
7	Get information from the Internet (26)	2
8	Lists equipment (52)	1
9	Brings out careers and jobs in scientific and technological fields (44)	1

Table 3 indicates that of the 11 pages in the chapter, 7 had at least one unit of text that presented a problematic view of science according to the Lewontin categorization scheme. It is worth noting that of the four other pages, one was a table of contents, two were instructional steps for activities, and one was drawings of newspapers. To get a clear picture of the subtext across the chapter, let us look at the context some of the pages in chronological order.

"Chapter 3: Need in the Midst of Plenty" is about water, and it begins with a general discussion. In the introductory paragraph, it raises the point that Quebec "holds one of the largest reserves of fresh water" and asks if it is "the same everywhere around the world?" and "what can we do to help people trying to cope with a shortage of drinking water?" (2008, p. 87). The first question does not prompt students to reason out or research an answer. As its Chiappetta code would suggest, this is a question that simply asks for recall of the information that immediately preceded the question. After all, if Quebec holds one of the *largest* reserves of water, it logically cannot be the same *everywhere* around the world. This question does not actually serve to prompt students to investigate. Rather, its function is to present the concept that the inequality of fresh water is an entirely natural phenomenon. Although nobody can argue the size of bodies of water, this page only presents half of the picture about access to water. While it is true that Quebec holds a large reserve of fresh water, the size or the mere existence of a body water is not the only factor that limits people's access to it. Lack of road access, transportation methods, sanitation, piping, and infrastructure all limit access to water. Many of these factors come down to poverty and the unequal distribution of wealth across countries but also within communities. Furthermore, the reasons for limited access to water vary according to region, culture, and local politics. Without considering these largely social and economic factors, it is almost impossible to effectively or realistically answer what we can do to help those without water.

The page following is a guide to the chapter. It lists the names and descriptions of activities which culminate in a chapter review activity that involves getting a grant from a fictitious organization to "award a grant to a developing country to help use its fresh water reserves more effectively" (2008, p. 88). This statement presumes that all developing countries are ecologically and politically identical. This chapter review activity also assumes developing countries would automatically benefit from technologies from "developed" countries, a prime example of Lewontin's critique that Science and Technology is often presented as an abstract, triumphal practice above any potential social ramifications. Students are instructed to research the developing country's “traditional methods,” ultimately to “convince the International Development Aid Fund to award a grant” to the developing country to “improve the health” of their population (2008, p. 95). The terminology of developing country, traditional methods, awarding, and improve is all highly loaded and not at all value neutral. As Lewontin argues, science “is part of the general process of education, and the assertions of scientists are the basis for a great deal of the enterprise of forming consciousness. Education in general, and scientific education in particular, is meant not only to make us competent to manipulate the world but also to form our social attitudes” (2008, p. 77). A chapter that centers around the scientific West getting a grant to help a developing country reinforces a power structure in which the West dictates to developing countries what they need and what is good for their health.

The first activity in the chapter is also an example of learning how to manipulate the physical world without necessarily seeing the social context surrounding it. In “A Liquid World Lies Underground,” the reader is informed that “[g]round water pollution is often mentioned in the media. The 'water table' is an expanse of ground water, formed by the permeation of rainwater, that supplies wells and springs” (2008, p. 91). The experiment goes on to develop two research questions: 1. How does ground water get contaminated? And 2. How can I simulate the spread of a pollutant in the water table? At first glance, this experiment provides students with the opportunity to learn about pollution and its effect on local water sources. However, when we read the procedure and analysis questions, although there is mention of how pollution spreads, there is no mention of how water gets contaminated in the first place nor what any of the effects of polluted water are. The experiment can give students an interactive experience of how water gets contaminated, but further activities or even simple presentation of facts or simple analysis questions could bridge the activity into a socially relevant lesson. The desired learning outcome of this abstracted activity is that ground water can get contaminated, but this is unlikely to come as a surprise to anybody. If indeed the text's desire is to teach students how to "see the world from a whole new perspective" and "develop reasoning skills" (2008, p. III), it would help if it gave students the opportunity to understand water contamination more comprehensively than simply being something that happens when contaminants enter the water.

The page after this activity discusses how to collect rainwater because "in many developing countries there are no aqueduct systems" (2008, p. 92). Here again we see the triumphal discourse of Science and technology and of the West. Instead of discussing local water contaminants or the political state of Quebec's water ownership, we have learned that water can get contaminated, and that "people in [developing countries] have to work very hard to get their water" (2008, p. 92) as opposed to readers in Montreal, where all we "need to do to get drinking water is turn on the tap" (p. 2008, 89). While all of these concepts are true, we must ask the educational purpose of the assembly of these particular concepts over, for example, discussing local water pollution and access issues. It is not value neutral that, in a chapter about water less than a dozen pages long, we learn about obtaining a fictitious grant to help an unspecified developing country while discussing our own situation only in mostly favorable terms.

In addition, this chapter actually presents very few scientific or technological concepts that the average student would not already know. Rather, it creates a discourse which pushes the idea that we in the developed West can help people in developing countries without having much knowledge about water systems at all. The textbook does not provide enough factual information or realistic experimentation to effectively do anything. Students are taught that water can get contaminated (2008, p. 91) but not how or why this happens, and then students experiment with how to collect rainwater in a very non-specific receptacle (2008, p. 92) and create a filter that likely does not actually filter bacteria (2008, p. 94) or the harmful toxins in water. As Lewontin says, “Science is more than an institution devoted to the manipulation of the physical world. It also has a function in the formation of consciousness about the political and social world” (1991, p. 77). In this particular chapter we learn that Montreal has a superior water system and that it is easy for us to collect and filter rain water. Developing countries, by contrast, need a grant to help them do this.

There are, at least, a few rays of hope in the chapter: at the end, there is a research activity entitled “Standards Ensure That Water is Safe to Drink,” that does ask three questions:

1. What could happen to people drinking water where standards were not met?
2. What are the main sources of water pollution?
3. How can we protect ground water from pollutants? (2008, p. 93)

These questions are important and could lead to socially relevant research; however, they are three short questions in an entire chapter. They are also sandwiched between the activity to collect rainwater, and how to make rainwater clear, which, at a secondary level of education, seems simplistic at best. In the foreword, the editorial team for *Eureka* claims to let students “study science by taking part of it” (2008, p. iii), however, it hardly seems like taking part when the activities are mostly comprised of following steps to simple activities. It would be exercise or teach more skills if there were challenges to collecting the rainwater such as gathering water a certain distance from the roof without losing water that splashes the surroundings, or only using material recycled from household goods, or even the specification that the receptacle needs handles strong enough to carry when full.

In sum, *Eureka* does not deliver on its promise to let readers take part in science or significantly develop reasoning skills. While a large portion of the sampled text presents information, much of it is not value neutral, as Lewontin cautioned. In Section 3, I discuss how we, as teachers, might adapt our approach to science so that we can encourage more critical thinking in the classroom. First, I look at *Connection* to see how it compares.

Results - *Connection*

The other Ministry approved English Secondary Cycle One textbook is *Connection* (2008). I performed the same textbook analysis for *Connection* as I did for *Eureka*. I first took random samples from the entire textbook and categorized them using Chiappetta et al.'s textbook analysis scheme. I then follow up with an analysis using my Lewontin-based scheme on an entire chapter.

Table 5

Analysis of random sample of Connection *according to Chiapetta et al. (results sorted by frequency)*

Rank	Subcategory description (code)	Frequency
1	Presents facts, concepts, principles and laws (11)	104
2	Requires the student to reason out an answer (24)	48
3	Engages student in a thought experiment or activity (25)	47
4	Asks students to recall knowledge or information (12)	20
5	Instructs the student to perform an activity or a step in a lab task (51)	9
6	Textbook goals (53)	6

7	Brings out the careers and jobs in scientific and technological fields (44)	5
8	Requires the student to answer a question through the use of charts, tables, etc (22)	2
8	Requires the student to make a calculation (23)	2
8	Lists equipment (52)	2
9	Requires the student to answer a question through the use of materials (21)	0
9	Get information from the Internet (26)	0
9	Describes how a scientist experimented (31)	0
9	Shows the historical development of an idea (32)	0
9	Emphasizes the empirical nature and objectivity of science (33)	0
9	Shows how science proceeds by inductive and deductive reasoning (35)	0
9	Discusses evidence and proof (36)	0
9	Presents the scientific method and problem solving steps (37)	0
9	Describes the usefulness of science and technology on society (41)	0
9	Stresses the negative effects of science and technology on society (42)	0
9	Discusses social issues related to science or technology (43)	0
9	Textbook mapping (54)	0

Like *Eureka*, the primary type of information in *Connection* was facts, concepts, principles and laws. There were very few clearly stated goals, links to jobs in Science and Technology fields, and even fewer activities that ask students to interpret information through charts, tables, and calculations. Unlike *Eureka,* the sampled text in *Connection* did not have text that fell under the categories:

- Requires student to answer a question through use of material (21)
- Shows the historical development of an idea (32)
- Presents the scientific methods and problem solving step (37)
- Describes the usefulness of science and technology on society (41)

- Textbook mapping (54)

It also did not have any text in categories:

- Get information off the Internet (26)
- Describes how a scientist experimented (31)
- Emphasizes the empirical nature and objectivity of science (33)
- Shows how science proceeds by inductive and deductive reasoning (35)
- Discusses evidence and proof (36)
- Stresses the negative effects of science and technology on society (42)
- discusses social issues related to science and technology (43)

This data indicates that there is not a large variety of types of information in *Connection.*

Looking at the broad Chiappetta et al. categories, we see the following:

Table 6

Chiapetta et al. categories in random sample of Connection (percentages)

Category	Percentage
Knowledge of science	50.61%
Investigative nature of science	40.4%
Science as a way of thinking	0
Interaction of science, technology, and society	2.4%
Instructions	6.94%

This indicates that half of the textbook relates to the knowledge of science, and no information describes science as a way of thinking. There is also very little mention of the interaction of Science and Technology with society (2.4%) and instructions to navigate experiments or the textbook itself (6.94%).

There were no samples of text that overtly discuss the negative effects of Science and Technology on society, nor were there any that discussed social issues related to Science and Technology. The only type of interaction of Science and Technology with society mentioned were the five times the textbook discussed careers and jobs in scientific and technological fields.

It is no surprise that the knowledge of science plays an important role in a science and technology textbook. However, as Lewontin has pointed out, and as it has been shown with the facts and concepts presented in *Eureka*, it is vital to the critically thinking classroom to look past concepts as an assembly of value neutral concepts. Once again, we see a positioning of science as a set of value neutral facts, and very little discussion of the contingent ways in which society is shaped by science and vice-versa.

For a closer look at the information in *Connection,* I will now discuss the chapter "Theme 4: Part 2: Human Beings and Epidemics." I read through the 24 pages of this chapter, coding with the Chiappetta et al. textbook analysis scheme, as well as the Lewontin scheme. I also look qualitatively at overarching themes and the creation of discourse through use of selective language.

Table 7

Analysis of whole chapter of Connection *according to Chiapetta et al. (results sorted by frequency)*

Rank	Subcategory (code)	Frequency	Percentage
1	Presents facts, concepts, principles, and laws (11)	71	37.76
2	Engages student in a thought experiment or activity (25)	30	15.96
3	Requires student to reason out an answer (24)	25	13.3

3	Instructs the student to perform an activity or a step in a lab task (51)	25	13.3
4	Brings out careers and jobs in scientific and technological fields (44)	16	8.51
5	Asks students to recall knowledge or information (12)	14	7.45
6	Get information from the Internet (26)	4	2.13
7	Lists equipment (52)	2	1.06
8	Requires student to answer a question through the use of charts, tables, etc (22)	1	0.53
9	Requires the student to answer a question through the use of materials (21)	0	0
9	Requires the student to make a calculation (23)	0	0
9	Engages student in a thought experiment or activity (25)	0	0
9	Describes how a scientist experimented. (31)	0	0
9	Shows the historical development of an idea (32)	0	0
9	Emphasizes the empirical nature and objectivity of science (33)	0	0
9	Shows how science proceeds by inductive and deductive reasoning (35)	0	0
9	Discusses evidence and proof (36)	0	0
9	Presents the scientific method(s) and problem solving steps (37)	0	0
9	Describes the usefulness of science and technology on society (41)	0	0
9	Stresses the negative effects of science and technology on society (42)	0	0
9	Discusses social issues related to science or technology (43)	0	0
9	Goals (53)	0	0
9	Textbook mapping (54)	0	0

This data indicates that this chapter mainly features facts, concepts, principles, and laws (37.76%), backed up by thought experiments, activities, (15.96%) and asking students to reasoning out answers (13.3%). At first glance, there does seem to be some promise in the fact that there are a number of activities that appear to call for critical reasoning.

Interestingly enough, the chapter starts out with an activity that tells students that "[j]ust because something is written in a book or magazine, or on the Internet, does not mean it is true" (2008, p. 147). Students are instructed to find two scientific errors in the article and "suggest corrections to make the article scientifically accurate" (2008, p. 147). This theme of discovery through activities and questions is actually, relative to *Eureka*, well done from an educational standpoint. The facts and concepts are presented without seeming excessively varnished or triumphal, there are no unnecessary anecdotes or filler that is irrelevant to the topic, and the activity is age and level appropriate for an activity in the middle of the textbook.

The next set of questions in the "Exploration" section of the chapter asks some questions whose answers might be difficult to manage in a class, but when asked in a safe and supportive manner by a knowledgeable and experienced teacher, can be informative and relevant to everyday experiences of students. For example, question (b) asks "What are the first three words that come to mind when you see [the name HIV]?" (2008, p. 150). If asked in an unsupported or unstructured way, this can open the gates to very hurtful and discriminating comments from students. However, if asked in a class where students feel safe to share their opinions without judgment and where they have a good rapport with the teacher, asking such an open ended question could be a fertile conversation ground for discussing stereotypes and common misconceptions. Further, the pages following these questions provide important facts about HIV and genetic material, their transmission methods, structured activities to look up further information, and a two-page activity on contagious viruses and the role of vaccinations. The experiment following this information helps students to understand how germs react to antiseptic solutions. The historical section then discusses how people used to treat contagious diseases but without denigrating “other” cultures or eras, and without making modern medicine seem overly triumphal. The next activity, “Reporters Without Borders,” asks students to write a report on an epidemic of their choice using the knowledge gathered from previous activities. The first half of the chapter is well structured; it presents facts and concepts and then allows students to learn more about them through specific questions, structured activities, and relevant experiments.

It is surprising then, that in the subsequent section, “Connection With Culture,” we read the story of “the young” Quebecker Dr. Lucille Teasdale who was “seduced by the idea” when Dr. Piero Corti asked her to accompany him to Uganda. It is described as a love story “between the couple and this poor, war-torn country” as they started a hospital to “improve the population's living conditions” (2008, p. 162). The rest of the page describes how Dr. Lucille Teasdale “remained active despite the disease, dedicating herself completely to the practice of medicine up until the time of her death” after being contaminated with HIV while operating on a soldier” (2008, p. 162). The story goes on to say, “[w]ith her husband, she created an Italian foundation charged with administering and carrying on their extraordinary work” (2008, p. 162). While this page highlights a woman's contribution to a hospital, it is also unclear what her contribution was, as her only clearly stated role was her role as a wife to Dr. Corti, and the only adjectives used to describe her are “young” and “seduced.” She is also said to have “cared for” soldiers and “remained active” in “dedicating” herself even while she was sick. So while this chapter is quite thorough in its presentation of facts and concepts in the rest of the chapter, its “Connection With Culture” is problematic. It is unclear what this version of “culture” is supposed to teach students other than the role of female doctors is dote on and support their heroic husbands as they become enamored by war torn Uganda.

Afterwards, we see a historic view of viruses and vaccines. Each event is kept short and to the point, without any excessive descriptors. However, it is notable that the scientists are almost all from first world countries. They are Greek, Roman, Persian, Hungarian, French, Dutch, Spanish, or American. It is undeniable that the upper classes in first world countries have more money, infrastructure, and education that allows them to experiment and study science and technology. It also logical that on a one-page historic overview, only a select number of scientists and discoveries can be chosen. However, it is highly unusual that, at very least, the practice of inoculation in China was not at all addressed. The earliest recorded cases of inoculation, the deliberate application of a small quantity of a virus to boost immunity and prevent a person from catching the virus, were performed by Chinese physicians. This makes the time line on vaccines in *Connection* rather incomplete, since inoculation is the grounding structure for vaccines. The omission of this foundational historical fact speaks to the Western triumphalism and is an example of Stuart Hall's (1992) notion of “West and the Rest” discourse.

In the “Integration”activity, the topic of critical thinking is directly addressed. It begins with an exercise where students are asked to recall when they “have just read a text or listened to a presentation on a subject you know little about” (2008, p. 166). The text then goes on to acknowledge that everybody reacts differently to new things and “taking a position might not always be easy!” (2008, p. 166). It also argues that “critical judgment is an essential ability you need to develop in order to assert and have confidence in yourself” (2008, p. 166) and continues to say that media might not necessarily present true information, and that not all sources are “good.” The text says that “a very simple tool” exists to untangle all the information: “learn to ask important questions. […] every time you ask a question, you give yourself an extra moment to reflect on and establish your position with respect to a piece of information" (2008, p. 166). True to the pattern established earlier in the chapter, the presentation of concepts is then followed up by an activity that gives students the chance to apply their knowledge. Page 167 has an activity where students are asked to question sources in relation to teacher-provided articles on SARS. This activity is very well structured; however, it would be even more effective to put it earlier in the textbook, at the start of the school year, so that critical judgment could be practiced throughout the year and not just treated as a one-off activity.

Conclusion

In conclusion, *Connection* has a lot less problematic content than *Eureka*. *Eureka* does not explicitly address science as a way of thinking, nor the interaction of science with society, but this adds to its mass presentation of facts that overall, implicitly present science as triumphal, excessively varnished, and a matter for experts. It does not encourage critical thinking, active participation, or the practice of scientific skills.

However, there are still a lot of problems which remain with *Connection*. While over half of the text presents the knowledge of science, there is not a single example of text that exposes science as a way of thinking. There is no mention of the negative effects the practice of Science and Technology can have on society, nor is there any acknowledgement of social issues related to Science and Technology. For the most part, *Connection* was good at presenting science and technology based facts and providing follow up activities to help deepen students' knowledge. However, when it came to the cultural and historical sections of the chapter, it fell short of its own standards in critical thinking.

In the following section of this thesis, I focus primarily on feminist approaches in order to suggest how these texts, and science pedagogy in general, can be adapted to be more relevant to students lives, more inclusive to a diverse student body, and in turn, to include critical thinking in Science and Technology.

Section 3: Theory in Practice

"Any educational system is a political way to maintain or to modify the appropriation of discourses, with the knowledge and the power they carry with them" (Foucault, 1980, p. 46).

Introduction

Critical thinking is an educational goal in Quebec but teachers are not trained to teach it and the required textbooks are written in a way that discourages it. In "Section 1: Critical Theory in a Nutshell," I outline the importance of critical pedagogy, and I discuss how Science and Technology is not value neutral. In "Section 2: Textbook Analysis," I analyze two of Quebec's Science and Technology textbooks and demonstrate how the material implicitly puts Science and Technology on a pedestal, alienating students and discouraging active participation. I argue that science as a discipline can theoretically be problematic, and then I demonstrate it using examples from Quebec curriculum. In this following section, Theory in Practice, I propose frameworks to reconsider how we teach Science and Technology, with the goal of fostering critical thinking and increasing race and gender inclusivity so that students can participate more actively in science. . The intersection of critical pedagogy and Science and Technology education has previously been studied by a variety of scholars and I begin by outlining some of their work in order to discuss what has already been tried and tested to get us where we are today. I then synthesize elements from various approaches to offer alternatives to our current curriculum.

In this section I build heavily on the concept of "ways of knowing." Much like Lewontin (1991), feminist scholars in science education challenge the idea that science is value neutral. While Lewontin (1991) was critiquing the atomised approach, feminist scientists question the idea that the scientific method is best practiced by "distancing themselves from their object of study, [controlling] their environment and their object, and [separating] and [fragmenting] knowledge so that it can be classified and categorized" (Barton, 1998, p. 7). This atomised method of finding and producing knowledge is prioritized over personal feelings, and acknowledgement of context and subjectivity (Barton, 1998, p.7). Hubbard (1986) argues that context and subjectivity must be acknowledged in science because they are part of being human, and we do not exist in a vacuum. Therefore, feminist scholars make the case for a more holistic approach to science that recognizes multiple ways of knowing.

An important part of this approach is differentiating between what is traditionally known as science for scientists, and scientific literacy. As we will see in the forthcoming section, science for scientists is comprised largely of already established facts, interpreted and passed down from specialists. On the other hand, scientific literacy is made up of the facts, vocabulary, concepts, history, and philosophy needed for the general public to understand public issues and discourse related to science.

What is the Purpose of Science and Technology Education?

A fundamental question to ask when discussing science education is: what is the purpose of science education? Answering this question brings focus to how we teach. Roth and Desautels (2002) look at the history of science education and identify an important premise in the discussion of critical pedagogy: if the goal of science education is to create the conditions for students to experience and replicate scientists' ways of knowing we will have vastly different teaching methods and outcomes than if our focus is centered on science for sociopolitical participation or scientific literacy. Roth and Desautels (2002) point out that in democratic societies such as the United States and Canada there is an increasing demand for public involvement in decisions pertaining to Science and Technology. However, there is a lack of participation from citizens who are not scientific experts. From an educational perspective, this lack of participation would suggest a need for a different type of science education, specifically one that increases scientific literacy among the non-specialized public. Roth and Desautels (2002) claim that the basic premises and foundational beliefs in science education have changed very little since their inception. They look closely at the concept of scientific literacy in action and found that, in practice, it was merely a recycling of past approaches: it is just scientific content that has to be acquired by students, akin to Freire's (1970) banking model. Roth and Desautels point out that curriculum aims for students to acquire scientists' ways of knowing as if that undoubtedly translates into critical social actors, and they argue that this view is mistaken. This means that the potential for sociopolitical action through science education is watered down. Regardless of changes in approach, the underlying message to educators and learners is the same: to teach and learn the science of scientists. But if we are going to empower students to actively participate in society, as we saw was necessary from Section 1, and if we want to adapt our lessons to meet the MELS requirements for critical thinking, we must envision a different way to teach science.

As educational philosopher John Dewey (1916) points out in *Democracy and Education*, science should be “that which we think *with* rather than that which we think about” (p. 196). Similarly, Roth and Desautels (2002) argue for a science curriculum that is relevant to students and empowers citizens with scientific literacy. They argue that while it was good that constructivists began putting focus on the learning process, it is important to dig deeper and change the underlying narratives that inform how we think about and teach science. They point out that the science of scientists is not the only goal to strive for in science education, but rather a science that allows every citizen to participate in sociopolitical action and democracy.

Science and Technology Education for Sociopolitical Action

A central concept in rethinking science education is how we think of learners and why it is necessary for them to learn science. Historically, models of public involvement were based on the notion that decisions in Science and Technology should be made by specialists. These models are based on the idea that the public has inadequate understanding of Science and Technology and would therefore be ineffective and unproductive in decision making processes (Roth & Desautels, 2002). Following this deficit view, the primary function of science education becomes the reproduction of social hierarchy, whether expressly or not. Here again we see the theme of Lewontin's vision of science as triumphal and being used as a measure of social legitimation.

However, if we want to teach Science and Technology so that students can actually use scientific reasoning and participate in democracy as Dewey and other student-oriented theorists envisioned, we must challenge how we think of learners and consequently the nature of knowledge itself. Roth and Desautels (2002) point out that learners have the capacity to appropriate learned skills for their own knowledge as they see fit for their lives. Instead of thinking of learners as blank slates in deficit like Freire critiqued, we can recognize them as people with interests, needs, and desires that can be fulfilled with Science and Technology education. This means rather than curriculum designers and educators teaching scientists' science, it would be more empowering to learners to teach them scientific skills they can use in every day life, increasing their scientific literacy.

As Hazen and Trefil (1991) point out, although we now live in a time which is saturated with scientific research and technology, many people do not feel they have control or understanding of their environment. We now live in an age of technology, and changes in technology are having profound effects on our culture, communities, and natural environment, and the worry is that students do not have awareness of how any of this new, life-changing technology actually works. This is indicative of a need for scientific literacy as a tool of democracy but also as matter of survival in our current society.

Learners' needs become especially important when considering that we live in societies of manufactured risk. Sociologist Anthony Giddens (1998) characterizes manufactured risk societies with an increased preoccupation with the future and safety while Ulrich Beck (1992) characterizes them as “a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself” (p. 21). Giddens and Beck both argue that modernity is characterized by a high amount of manufactured risk, that is to say, risks that are produced and potentially mitigated by humans. A boomerang effect occurs when the individuals who produce the risk also become exposed to their effects, creating more risks. For example, when wealthy people's consumption habits produces pollution, the pollution contaminates the water. that while wealth may help people manage risk by buying bottled water, education and knowledge play a more central role in mitigation because people need to know that there is a risk in the first place, and once the risk is understood then buying bottled water would create more risks in terms of pollution and the long term effects of production of water bottles.

If we want to teach students critical thinking so that they can make good decisions in our society of increasing manufactured risk, we need to teach scientific thinking as a process and a skill, not science as material that is simply proven facts passed down from specialists who have already interpreted them for us. This means shifting focus from teaching and learning disciplinary knowledge towards teaching scientific skills so that learners can make critical decisions about the world in which we live. Instead of the science of scientists, we should be teaching scientific literacy. I use Hazen and Trefil's (1991) definition of scientific literacy, which encompasses the facts, vocabulary, concepts, history, and philosophy needed to understand public issues related to science (p. xii). This knowledge is not the highly specialized science of experts but the general knowledge used to understand scientific discourse. Hazen and Trefil's (1991) litmus test for scientific literacy is if you can understand the daily news in relation to science, then you are scientifically literate. Although this definition seems rather minimalist, it is important to point out to those who insist on a deeper understanding of all sciences that there is a difference between doing science and using science. The ability to use science is what I consider to be the goal of scientific literacy.

Socio-Epistemological Complexities

Scientific literacy as a necessary tool for sociopolitical action has a complex history. Jenkins' (2002) research points out that most pedagogical solutions in the past have had minimal effect in transforming traditional science education because the underlying ideology is grounded in a positivistic epistemology. Positivism is a major obstacle in face of science education for sociopolitical action—in positivist approaches, the only type of valid knowledge is that which is derived from sensory experience and interpreted by reason and logic. It relies on laws of the physical world. Consequently, it is harshly against introspection, and intuitive knowledge – elements that are crucial for a curriculum that claims to foster critical thinking and as we will see later in this chapter, more traditionally feminine ways of knowing. As I will later expand upon in my discussion of second wave feminism, the central premise of positivism is that science must be "largely free of personal, social, and cultural values and distorted one-way views of the world" (Barton, 1998, p. 5). However, this championing of objectivity and atomization above all presents a very specific type of scientific practice, and it is an incomplete picture if we wish to include multiple ways of knowing or doing science. Furthermore, it should also not be forgotten that on the larger scale, formal education in schools is:

> the main social process through which particular discourses are culturally reproduced and thereby establish their domination in the public sphere. Therefore, the central question of power/knowledge as framed by Foucault always has to be in the back of our minds" and by extension "...any attempts to promote scientific literacy as a goal for science education should take into account the complexities inherent in this social endeavor. (Roth & Desautels, 2002, p. 9)

As we saw from Freire (1970) and Foucault (1980, those who have power define what is important knowledge, and can guard their power by limiting the sharing of that knowledge. Furthermore, we must consider that major backers of research in Science and Technology have vested interests in their progress, such as the military and transnational companies. Science and Technology, both in theory and in practice, are deeply political, regardless we recognize them as such or not.

Consequently, if we want to share the power and educate learners in a way that will help them participate in society and the production of knowledge, we need to challenge the classic representation of traditional science as “intellectual feats enabling human beings to decipher the secrets and the order of nature has been fractured” and catch up with the emerging research that emphasizes “the local and contingent nature of scientific practices” (Roth & Desautels, 2002, p. 9). We need to challenge the idea of science as an objectively neutral way of accessing truths.

Traditional science education is not helping students be active participants in democracy. Roth and Desautels (2002) point out that only a small percent of students take science past the mandatory grade and “many adults claim that they do not understand science and hated it as school subject” (p. 10). This produces a harmful cycle that is both counter democratic and counter educational. Traditional science education and the training of scientists shakes people out of the system and those who are classified as worthy of becoming scientists have a significant influence on society. This raises questions like, “Is this the kind of science we want to teach?” and, “Do we want to continue to use science education as a career selection mechanism or do we want science for all?” and “What would be an appropriate science that takes seriously the words 'for all'?” (Roth & Lee, 2002, p. 68).

There is a lack of transparency in the type of knowledge traditionally championed in schools. When we treat knowledge as a static commodity that can be straightforwardly transferred by one person to another without framing or contextualizing it, we are taking a “fact transferal” approach. In this approach, students memorize, often without understanding, facts and theories without engaging with them, which creates a schism between traditional school knowledge and everyday practical knowledge.

Many thinkers have long argued on various grounds – including pragmatist (Dewey, 1933), phenomenological (Heidegger, 1977), and Marxist grounds (Bourdieu, 1997) – that much of what we know results from our experience of acting in the world, and in terms of the community of which we are necessarily part. (as cited by Roth & Lee, 2002, p. 73)

Instead of thinking of science as inherently worthwhile knowledge that should be learned for its own sake and can be transferred context-free, a critical focus proposes that educators define scientific practice in relation to the everyday needs of learners.

Furthermore, many philosophers feel that knowledge is best viewed as an active resource rather than a passive stock. Knowing and the acquisition of knowledge is an action and because actions happen within a social context, action is inherently situated. Therefore, knowing is constituted from our interactions with the world, not memorized facts or statements in a social vacuum. Roth & Lee (2002) use the example of writing on a computer: to successfully type a sentence on a computer, we do not need to think about how word processors work, or even which individual keys to type, because we use them in context of how they suit our needs. Most of what we know about how to use computers does not entail how computers work on a hardware or software level. While it is important to have software engineers and computer scientists, it is not relevant or empowering to teach learners who want to write an email or resume how to program. By the same token, it would be more socially relevant to teach Science and Technology as it relates to learner's lives, and not just scientists' science. Dewey (1916) goes further back and situates the desire for theory over practice as far back as the works of Plato and Aristotle. According to Dewey, these philosophers' distrusted practice over theory because they saw practice as privilege to study and though practitioners had reliable knowledge, it was thought to be limited in scope and formulaic. To practice meant having little knowledge, and to commit oneself to purely practical activities meant shutting doors of the mind and fating oneself to routine (Dewey, 1961, p. 261).

A Practical View of Science and Technology Education as Social Action

According to situated cognition theories, we learn early on by participating in communities. This means that the bulk of our knowledge is learned by participation in community life, not by explicit lessons. This can be seen with the previous example of typing on a word processor, where we learn by doing and may not understand the mechanisms that underlay the technology, but also in many other examples in human development such as learning our native language; children learn vocabulary through use with other people in their environment, not by first learning grammar and speaking in "correct" sentences. Later in life we can also see adults who know how to communicate with others in a grammatically correct manner without being able to explicitly explain grammatical rules. This can also be seen in practical trades whose specialists were trained through apprenticeship. For example, tailors learn their trade by increasingly participating in daily productions (Lave, 1977), and Mayan midwives acquire knowledge and skills through participating in an increasing amounts of daily activities relating to pregnancy, story-telling, and birthing (Jordan, 1989). What is important to note about these examples is that the learner is learning based on their participation and increased responsibility in tasks that constitute the role. They are not doing inauthentic activities that are modularly designed to make them learn information that is later to be applied in a different context (Roth & Desautels, 2002, p. 7). For instance, remember the activity in Section 2 that asks students to build a mini green house. At first description this sounds like a rich educational activity but upon closer look at the specifics, we see how abstracted the calculations and procedures are. It is not just a matter of doing activities so much as doing activities that are compelling for students and offer them transferable skills and contribute to their scientific literacy.

Considering these examples of learning, it is useful to consider science education in the scope of how it relates to people participating socially, rather than just memorizing scientists' science. As highlighted in these examples, the participation has obvious relation and benefit to the learner's life and community. As Roth and Lee (2002) specify, "we are more interested in how people do 'science' than whether they can recite fragments of scientific discourse or interpret engineers' technical inscriptions. When planning a meal, building a compost pile, taking a child for a nature walk, how does a person make sense of and act appropriately toward their physical surroundings?" (p. 38). Roth and Desautels (2002) even draw this point a step further based on Rowe and Frewer's (2002) research that "public participation in policy making in science and technology is necessary if society is to reflect democratic ideals and to enhance trust in and transparency of regulatory systems" (as cited in Roth & Desautels, 2002, p. 8). The important question then becomes *how* educators can create the optimal learning conditions to prepare students for this type of participation. These skills translate to scientific literacy.

Scientific literacy includes knowing how to find scientific resources and tools and how to appropriately apply them as the situation sees fit. This is in contrast to traditional science education which focuses more on the acquisition of knowledge that already has been deemed true by scientists (Roth & Desautels, 2002, p. 4). In sum, scientific literacy is not the memorization of scientific facts but rather a wide array of resources and methods, and the ability to use them appropriately.

There are multiple ways to approach scientific literacy. One promising approach focuses on the teacher engaging students so that students can transform their reality. Another, perhaps more radical, approach focuses more on the learner, and considers science education as a by-product of students' engagement in social action. In this approach, learners affect change on their community through their actions. In either approach, knowledge is necessarily located in its social context.

To give a more concrete example of what scientific literacy looks like, we can refer to the work of Belgian philosopher Gerard Fourez. In 1997, Fourez made a list of some major practices scientists engage in, whether they were an engineer or an environmental activist. Based on these activities, he defines scientific literacy as "the skillful use of experts; black boxes; simple interdisciplinary models (rationality islands); metaphors, comparisons and images, translations; standardized and disciplinary knowledge, and rationality in the process and making decisions" (p. 911). Fourez's (1997) checklist for scientific literacy looks like this:

- Right use of specialists.
- Right use of black boxes: this is the ability to judge when not to open a phenomenon up to analysis, but rather to just let it do its thing. That is, we do not need to know how a computer keyboard informs the CPU of the letters we are pushing, we are happy to use it as a black box.
- Right use of simple models: this is knowing when a situation needs to be explained theoretically, for example, what model would be appropriate to work out when it is

convenient to pull and when to push a wheelbarrow?

- Right use of interdisciplinary models: this notion refers to the invention within the context of a specific project, of an adequate model – fairly simple but using knowledge stemming from various disciplines as well as from the know-how of everyday life.
- Right use of metaphors.
- Right use of standardized knowledge (scientific disciplines): This means that students have to be inducted into established views and methods, that is, those that have been successful and without which it would be practically impossible to communicate within a scientific and technical society.
- Right use of translations: This is the skill of translating standardized knowledge into representation of everyday life, and vice versa. It is the ability to contrast the understanding of a technology with the understanding of its scientific principles. This refers to the difference between understanding how and when to use a fax machine as opposed to email or telephone (technological understanding), and understanding the scientific principles behind a fax machine's operation.
- Right use of knowledge and decisions, pertaining to how we teach young people to relate scientific and technological knowledge to ethical and political decisions. (p. 911-923)

This list can serve as a helpful guide when designing lessons in Science and Technology. An activity or lesson that features many of the elements listed is likely to encourage or allow students to practice scientific literacy. At very least, it gives definition and examples to the abstract notion of scientific literacy.

In sum, I began by asking what the purpose of science education is. Traditional science education is based in banking scientific facts to learners. It treats knowledge as static information to be transferred to students. Critics argue that this approach alienates students from the discipline and does not equip citizens to make informed decisions or actions in relation to the world that is increasingly science and technology based. Instead, critics such as Roth and Desautels (2002) propose an approach that focuses more on scientific literacy. This approach is based on the idea that knowledge is socially located and as such, should be relevant to learners' lives.

Now that we have looked at a new approach to science literacy and critiques of the traditional approach, I will take the discussion a step further and look at the history of science education in relation to feminist philosophy.

The Feminist Classroom

As discussed in the previous section, traditional science education fails to equip students with the tools to deal with an increasingly science and technology-rich world, and teaching the science of scientists upholds hierarchical power structures in society. In this section I will look at how science has historically done this to the disadvantage of female learners, and how different waves of feminism brought change to science education in order to make it more accessible, socially relevant, and gender equal. I begin by discussing equity issues that were brought up by first wave feminists. I then look at second wave feminism's analysis of science including the nature of science and scientific knowledge, constructed ways of knowing, and relationships between science and society, and the gender-inclusive science education that came as a result of these analyses. Through third wave feminism I look at situated ways of knowing, especially considering the intersection of gender, class, and race, and the notions of self-reflexivity and truth regimes.

It is important to note that feminism, in all its waves, is a political movement with the goal to change oppressive practices and beliefs. Therefore, it sees “science and curriculum as political texts,” schools as “legitimizers of hegemonic ideals,” and “recognizes and draws its strength from teachers and students as agents and actors who actively and collectively shape and reshape their own understand of the world from specific standpoints” (Barton, 1998, p. 15). This means students and teachers have the power to construct knowledge of science, education, ourselves and others, and that this knowledge is “historically and politically contextual and also changeable” (Barton, 1998, p. 15). The epistemological understandings are the foundation for the deconstruction of scientific knowledge as we traditionally knew it, and for the construction of alternatives (Harding, 1986; Smith, 1987).

First Wave Feminism: Issues of Equity

First wave, liberal, feminism played a significant role in science education by emphasizing ways to bring women and minorities “into” science. The movement highlighted the ways women and minorities were prevented or highly discouraged from studying science and also points out that careers in science are not equally accessible across genders. Kahle and Meece's (1994) research of early science education found that:

> women were actively and passively blocked from entering the sciences in numbers equal to those of their white male counters: classroom activities that promote perceptions of science as dull, only for smart people, only for boys, and not connected with personal experiences; a lack of role models, after-school

> programs and incentives; science teaching practices that perpetuate scientific knowledge as objective, rational, male, and mechanistic; family and home structures that promote traditional roles for women; and educational practices that emphasize boys' over girls' achievements in science. (as cited in Barton, 1998, p.3)

Identifying these roadblocks lead to the creation of programs to increase the number of women in science. The goal of these programs was to demystify science to girls and provide career information and role models. The programs purposely sought to raise girls' self-confidence and perception of their ability to do science by having activities that actively involved girls (Barton, 1998, p.3)). In sum, first wave liberal feminists largely fought for women to get their foot in the science classroom.

Second Wave Feminism: Gender-Inclusive Science

First wave feminism worked at issues of equity and sought to include women and minorities in sciences, and to create programs that included them specifically. While research into equity was a huge building block in science education, it put the brunt of the responsibility to change pedagogy on already marginalized women and minorities. First wave feminism invited women to the science club, then second wave feminism began to look at the mandate of the club and proposed that the rules needed to be changed. It is not enough to have girls in the class if the structure of the class itself is still oppressive in nature.

During the 1980s and 1990s, second wave feminism turned the microscope on scientific practice and culture itself. Second wave feminists looked at “multiple ways of knowing and doing science that are reflective of the social, historical, and political context in which science has been constructed and in which students learn that science" (Barton 1998, p. 4). Second wave feminists studying pedagogy in science such as Harding (1986), Hubbard (1986), Fox Keller (1985), and Longino (1990), focused on the nature of science and scientific knowledge, ways of knowing, and the relationship between science and society.

Second Wave: Nature of Science and Scientific Knowledge

Feminist philosophers of science like Sandra Harding (1986) and Evelyn Fox Keller (1985) analyzed positivism, which they considered to be one of the most powerful intellectual traditions of Western society. The foundation of positivist science is the premise that "all scientific facts are grounded in sound scientific theory, largely free of personal, social, and cultural values and distorted one-way views of the world" (Barton, 1998, p.5). Like we saw Roth and Desautels argue in their approach to science education for sociopolitical action, second wave feminists point out that "this positivist ideology is reflected in the scientific premise of science and scientific knowledge, and in the authoritarian nature and powerful position of science in society" (Barton, 1998, p. 5). Researchers in different fields began noticing the androcentric nature of their disciplines, and questions of epistemology were raised: "it became apparent that alternative accounts of knowledge and of justification were required in order to overthrow presuppositions in their disciplines which functioned as obstacles to necessary change" (Longino 1999, p. 330).

This translated to second wave feminists challenging the positivist concept of objective science. They posed the social constructivist question: "does value free science education exist?" and argued that it did not. According to Barton (1998), there are two types of values: constitutive values that define acceptable scientific practices, and contextual values which include the personal, social, and cultural values surrounding the practice. While popular scientific ideology would have us believe that the former exists without the latter, second wave feminists argue that contextual values are heavily tied to the constitutive and that both play significant roles in the scientific process. Scientific inquiry does not happen in a society and value free vacuum: it begins with a question posed by a person, or a problem experienced by a person. Hypothesis and theories are thought up and worked on by people. Therefore, scientific practice is "vulnerable to human action and interaction" (Barton, 1998, p. 5). One need only to visit a local library or bookstore's science section to see a myriad of scientific books written with local cultural interests in mind. The political, cultural, and socioeconomic climate within which a scientific question is posed is inextricable from the process of scientific inquiry. Likewise, the interpretation of results is done in the same climate. Society then becomes a guide to scientific inquiry and the interpretation of results. Research depends on outside sources for funding, and scientific inquiry is often done with this dependency in mind. Second wave feminists argue that awareness, and admittance of, these influences dismantles the idea of scientific objectivity and value-free science.

Vulnerability to human action and interaction also makes scientific inquiry and the knowledge we gain from it highly susceptible to human bias. Since science was founded, defined, and initially performed exclusively by men, it is male-biased as a discipline. Science is deeply entrenched in the normative values of heterosexual, middle-upper-class European values. In practice, this means that the data and knowledge gained by scientific inquiry is partial or distorted and represents an "excluding knowledge" (Barton, 1998, p. 6).

Harding (1986) uses evolutionary studies as an example. In this field, scientists look at interactional behavior in relation to the development of human anatomy, and uses results to justify biologically determined sex roles. Harding's results revealed the tendency of the scientists to project racist and sexist understandings on that of apes and yet continue to be referenced to justify and perpetuate male dominance over women. These androcentric assumptions are present in the collection, interpretation, and use of data and are an example of value-filled and non-objective science. Here we see a clear example of science being influenced by, and continuing to uphold, ideological hegemony. Harding argues that other examples exist but do not get noticed because of the value system of beliefs that is so deeply entrenched in our daily lives. This parallels Hall's notion that discourse is pervasive and has significant power to affect how we talk about and conceptualize each other and our places in the world. In order to eliminate these foundational androcentric assumptions, gender must be recognized. Women's experiences are equally as valid as a man's and scientific inquiry should reflect this by giving voice and making space for questions that originate in female and non-binary gendered experience. Until gender is openly acknowledged, science will remain an exclusive and exclusionary discipline (Barton, 1998, p. 6).

Feminist scholars of science education agree that gender- and value-free science does not exist and probably cannot in our current lifetimes. For a neutral science to exist, scientific knowledge as a whole would have to have eliminated bias, both in the generation of questions and the interpretation of answers. Instead of trying to control variables based on social influences, we should aim to understand and acknowledge such influences. Then, our understanding of science would be highly interactive and complex. This can be done in addition to some of the traditional scientific practices without diminishing their rigor. If science ever strives to be value free, it must first recognize the social forces and biases that shaped its foundations and continue to shape its knowledge base. As Barton (1998) points out, “This will enable the constructor of knowledge to create scientific statements that are more inclusive through a more complete understanding of the social forces that shape knowledge” (p. 7).

Second Wave: Ways of Knowing

Another aspect of the science education that second wave feminists look at is scientific ways of knowing. It is generally understood that science is performed by scientists distancing themselves from the subject of their experiments. Scientists look at a specific subject in highly controlled environments and knowledge can be classified in categories. Science, then, is defined as a specialized activity performed in a social vacuum. As Hubbard (1986) said:

> Scientists attain their objectivity by looking upon natural phenomena (including other people) as isolated objects that exist outside the context of interrelationships in which human beings are a part. Scientists describe their observations as though they and their activities existed in a vacuum. (p. 20)

Feminist scholars of science education call to the gallows the idea that science is best performed when subjects are abstracted from their environment, and question the assumption that knowledge supposedly gained apart from social context is more acceptable than other methods of discovery. Feelings and relationships are seen as impediments to objectivity, and the complex social and personal aspects of individuals are seen as problems that are reducible aspects of nature that can be overcome by science.

Instead, feminists analyzing science education argue that the complexity of individuals, including their feelings and relationships with each other and their environment, can be important factors in the discovery and creation of knowledge. Feminist theorists such as Hubbard (1986) assert that scientists need to acknowledge context and subjectivity in the practice of science because they are simply part of being human and it is humans performing science. Similarly, looking at the context of learners will help educators identify the skills necessary to develop scientific literacy that is relevant for their community. Traditional science analyzes data as separate pieces in a vacuum and claims to be objective but second wave feminist science scholars like Longino (1990) argue that this process oversimplifies the complex ways people relate to and comprehend the world, and its treatment of information as distinctly separate from culture further distorts reality.

Second wave feminists also studied ways of knowing in other disciplines, such as psychology. Psychological studies have pointed out how female students have been socialized to view problems holistically, and how these ways of knowing are devalued in patriarchal society (Belenky, Clinchy, Goldberger, & Tarule, 1986; Gilligan, 1982). This has consequently lead to focusing on reason, logic, mechanism, and reductionism over the more female ways of knowing (Barton, 1998).

Relationship Between Science and Society

A third aspect of science education that feminist scholars analyzed was the relationship between science and society. The goal of science since the 17^{th} century has been the manipulation of nature. Through the hegemonic ideologies of objective inquiry and the infallible reasoning of the scientific method, science became ideologically invincible to critique. In turn, scientific knowledge became as powerfully written in stone as the religious doctrine that came before it. Fox Keller (1985) argues that the struggle for power and dominance over nature is:

> grounded in the fear of being controlled by others rather than apprehensions about the loss of self-control, in the fear of giving in to others rather than to one's own unwelcoming impulses, the attention of paranoid is rigid, but it is not narrowly focused. Rather than ignore what does not fit, he or she must be alert to every possible clue. All clues fit into a single interpretation with no room for alternative explanations. (p. 121)

This singular interpretation is reflected in competing one's strength against the submission of another's. In other words, it is "the dream of the dominion of science over nature" (Fox Keller, 1985, p. 125). On top of fighting for recognition and power in society, a power pyramid exists within the scientific community. The hierarchical structure in research labs and within schools, as well as the competition for funding and recognition between scientists and their respective research projects, creates a power pyramid within scientific communities themselves.

In sum, second wave feminists argue for the inclusion of perspectives, insights, and experiences of women (Barton, 1998, p. 9). They counter the positivistic myth that there is one correct, objective way of doing science by analyzing elements as separate pieces to produce unbiased knowledge by pointing out that science is performed by scientists who are human and prone to bias, ambition, and who act within social conditions (Fox Keller, 1985; Harding, 1987, 1991; Longino, 1990).

Practical Implications of Second Wave Feminism in the Classroom

Much of the research done by second wave feminists and feminist philosophers has a foundation of social constructivism (Roychoudhury, Tippins, & Nichols, 1995). Viewing science as being affected by social forces led to advocating for recognition of multiple ways of knowing and the inclusion of marginalized perspectives. The impact of second wave feminism on science education can be seen in the shift to incorporate marginalized ways of knowing and aiming towards gender-inclusive science.

Feminist researchers in science education such as Brickhouse (1994) propose that science teachers can use social elements to value different ways to know, perform, and understand science in ways that traditionally have not be practiced. Traditional science is characterized by reason, logic, authority over nature and others, all values that are considered to be “masculine” and which are valued in boys and men. In contrast, girls are taught to value relational knowledge and connection within communities rather than competition and authority, and these ways of knowing, which are perceived to be “feminine,” are devalued. This discrepancy leads to girls feeling a high level of student alienation from science (Barton, 1998, p. 10). This means that science education must use students' experiences outside of traditional science if it wants to be more inclusive. Marginalized ways of knowing such as caring and cooperation must be valued in order for science to become accessible, interesting, and relevant to the wider student body and to become more than a system of social legitimation, upholding the gender imbalanced status quo.

Gender-Inclusive Science

It is important to specify that an inclusive science education means critically challenging the conceptual framework of traditional science. This means “rethinking the nature of science and science education" rather than "trying to reach equality in the sciences through the implementation of compensatory programs" (Barton, 1998, p. 11). This rethinking of science education steers research towards inspecting ways that traditional science's discourse and epistemology can be marginalizing to many students. Barton (1998) has argued that gender-inclusive science education can be defined by four characteristics:

a. recognizing scientific knowledge as socially and culturally bound, looking at how social context has influenced what is studied, developed and accepted;
b. acknowledging nature's complex and interactive existence with an emphasis on interactive relationships over the linear and isolated, and democratic approaches to the scientific community as well as nature instead of authoritarian power pyramids;
c. highlighting scientific contributions from marginalized groups; and practicing science through multiple ways of knowing, including female ways of knowing and relating that encourage collaboration, cooperation, and caring. (p. 11)

Teaching gender-inclusive science often means teaching beyond what has been taught in teacher training courses, as well as challenging ideas about science that could already be long ingrained in students. It requires a vast knowledge of science and the contexts it was performed in. It also requires knowing students' backgrounds well enough to engage them in ways that are meaningful for their lives. It requires teachers to go beyond the standard school curriculum of facts, theories, and procedures and delve into the history of science. It means teachers need to have knowledge of the sociocultural climate of the time that the experiments that "prove" standard facts and theories were performed in. It also requires teachers to have an awareness of the student populations that constitute their classes. Knowledge of historic context and complex student bodies in combination with the skill to turn this material in engaging lessons is what will make science relevant to current students.

Without this knowledge, educators will continue perpetuating a curriculum that is exclusionary and limited in its relevance to the diversity of real student bodies. If teachers continue teaching traditional science uncritically, teachers will continue to alienate students and not teach the scientific literacy required for students to actively participate in society.

It is commonly understood by feminists and non-feminists alike that science as taught in schools is “static, objective, rational, and mechanistic” (Barton, 1998, p. 12). This fact is sown, grown, and perpetually fruiting through science education curriculum. Even when classroom activities claim to be student centered and hands-on, they still focus on the acquisition of technical jargon and irrefutable facts that are decontextualized from social, historical, cultural, and political influence (Roychoudhury, Tippins & Nichols, 1995).

When a science curriculum has a set of predetermined correct answers, teachers educated with a narrow definition of science themselves can often encourage rational and “intellectual” discourse and squelch the more non-traditionally scientific approaches that involve the emotional and personal (Barton, 1998, p. 13). In these scenarios, pedagogical discourse trains students to learn how to speak the science of scientists by thinking and making judgments within the constraints of a positivistic paradigm that has already excluded alternatives throughout history (Barton, 1998, p. 13). As seen in “Section 2: Textbook Analysis,” experiments are designed with a designated goal and learning outcome, and that is to prove a theory that has already been proven by a scientist. This means students are exposed to a very rigid and constrained version of science. Curriculum experts can write, and teachers can say, that established scientific facts are theories, and concepts are open to change, but the reality is that teachers are teaching material with a vision of a singular "correct" answer. Gender-inclusive science, born out of second wave feminism, aims to challenge these rigid truths and be inclusive of multiple ways of knowing.

In conclusion, second wave feminists argue for a science program that looks beyond the traditional memorization of facts, theories, and procedures. A critically conscious and more inclusive science curriculum includes "learning about the norms, beliefs, values, and discursive practices, and ways of acting and reasoning that are acceptable within the community of scientists" (WISE, 1994, 1995, as cited in Barton, 1998, p. 12). It also highlights the ways and reasons scientific practice has been constructed and how that has excluded marginalized groups from entering the community (Barton & Osborne, 1995; Brickhouse, 1994; Hazelwood, 1996; Roth, 1995). In order to make science education more inclusive, Barton (1998) argues that "the ways of knowing and doing science of those not traditionally part of science culture must be validated and connections and divergences between such experiences and the traditional ways of knowing and doing science must be made explicit" (p. 12).

Third Wave Feminism: Situated Learning

Both first and second waves revealed gender-based inequalities in the classroom and attempted to gain equilibrium through gender-inclusive curricula and increased accessibility and representation in science for girls. Both waves highlighted gender as a source of inequality. Girls are socialized to prioritize relational information and to be caring, communal, and emotional, and scientific discourse teaches a rigid vision of science that is based on rational, detached thinking. This impedes multiple viewpoints from succeeding, and alienates girls' participation. First and second wave feminisms were largely separatist between genders, and essentialized the experience of what it means to be a girl or woman while third wave feminism delves a step further into analyzing the division in the classroom. Third wave feminists point out that first and second wave feminist theory grew out of the lived experiences of women who still shared many of the privileges of their fellow white, bourgeois, and intellectual male counterparts. Third wave feminism brings a trifocal lens to the lab by focusing on race, class, and gender (Amos & Parmar, 1981; Anyon, 1984, Gaskell, 1992; Luke & Gore, 1992, Middleton, 1993; Weiler, 1988).

While it is important to point out that girls are socialized in ways that are not encouraged in the traditional construct of science, third wave feminists specify that socialization includes other significant factors such as race and socioeconomic class. Third wave feminism is also characterized by self-reflexivity. According to Barton (1998), “it has utilized what was learned from earlier feminist work for an understanding of the situatedness of gender relations and knowledge within the larger context of disciplinary power” (p. 14). Third wave feminists recognized the power they have to define gender relations or to portray singular truths. This self-reflexivity means third wave feminists acknowledge the situated nature of knowledge, power, and authority. Foucault (1980) points out that every society has a regime of truth composed of discourses that it accepts as true, that is subject to constant incitement, and that:

> is object, under diverse forms, of immense diffusion and consumption (circulating through apparatuses of education and information whose extent is relatively broad in the social body); it is produced and transmitted under the control, dominant if not exclusive, of a few great political and economical apparatuses (university, army, writing, media); lastly, it is the issue of a whole political debate and social confrontation (ideological struggles). (p. 131-132)

Third wave feminism seeks to situate itself within its social context through self-reflexivity and challenging the regime of truth.

Third Wave Feminism in Science Class

Third wave feminist scholars of education believe that science education has traditionally been exclusionary towards “multiple narratives, histories, and voices of culturally and politically subordinated groups” (Barton, 1998, p. 16). This feminism has challenged not only how science is taught but what scientific knowledge entails by pointing out that science is not value-neutral. Science is as value laden as any other activity within the context of a culture, and science education “has been used to license cultural differences in order to regulate and define who scientists and science educators are and how they might narrate themselves” (Barton, 1998, p. 16). Accordingly, third wave feminists embrace subjectivity and look for ways to openly incorporate learners' identities and narratives in order to have a more inclusive and empowering science education.

It is also important to situate science within a larger global context, and be keenly aware of the discourse used when speaking globally. Scientific representations of the natural world are “central to understanding how the dynamics of power, privilege, and social desire structure the daily life of society. This demands a close examination of the connection between the production and use of scientific knowledge and authority” (Barton, 1998, p. 16). Third wave feminists, like Freire, reject the idea that scientific knowledge is a static body of information just waiting to be deposited to students who are empty banks. Therefore, the role of the educators and learners must always be challenged and situated. In this view, educators constantly situate their work within “larger contexts of culture and community, power and knowledge” as well as creating the "dynamics of social power through the experiences that they organize in classrooms" (Barton, 1998, p. 17). Teachers are constantly reflecting on explicit and implicit knowledge since teaching inherently involves learning.

More precisely, third wave feminist science education according to Barton (1998) has the characteristics of:

> exploring the ideologies that justify power inequalities,breaking silences,disrupting power relations,daring to decenter science,articulating what is possible and constructing different realities and, experimenting with alternative ways of learning and knowing. (p. 18)

In sum, third wave feminist research in science education suggests that if the goal is to have a curriculum that is inclusive and relevant to all students regardless of their gender, race, and socioeconomic class, educators and learners must analyze and re-create science in significant ways. Educators need to help students reflect on science, its history, and its political agenda, in order to construct a science that represents the complex intersection of identities of students in the classroom.

Contextualized in the Quebec Classroom

In Section 1, I gave a broad view of theorists to discuss how the practice of science is socially influenced and how science and science education influence society in turn, particularly through social legitimation and participation in ideological hegemony. In Section 2, I illustrated this with data analysis of Quebec Science and Technology textbooks. In this current section, I have been outlining different feminist approaches to scientific literacy and education with the goal of offering strategies for teachers to use in the classroom. I focus on scientific literacy and feminist approaches because they have significantly informed my own practices as a teacher. They meet curriculum requirements to cover material and foster critical thinking, while still using the Ministry approved textbooks. In this concluding section I offer the beginnings of discussion on how to link concepts in philosophy of science with feminist approaches. I begin by highlighting the importance of self-reflexivity, and then continue by discussing how teachers can start the school year by relating the concept of intersectionality to their everyday work in science class.

Self-Reflexivity

We saw earlier how third wave feminism places importance on self-reflexivity. This concept is crucial in my classroom and personal practice. If we as teachers are asking students to think critically, it is vital that we think critically ourselves. In science education, this means being aware of critical approaches to Science and Technology, like those of Lewontin. It also translates into understanding concepts of discourse and ideological hegemony so that we can recognize how science has been constructed as an institution. By familiarizing ourselves with the concepts in Section 1, we can demonstrate critical approaches and self-reflexivity to students by thinking carefully about our methodology and material. By questioning our course content, we are actively becoming part of the education process – both the students' and our own. It is through this active participation with the curriculum that we become intimately involved with teaching it. As Parker Palmer (1997) says, “we are who we teach”, and if we ourselves are not actively involved in our education then we are passing on to students the skills of passive information absorption and regurgitation (p. 1).

Philosophy of Science and Feminist Approaches Combined

In Section 1, we saw how the process and product of science are intertwined within society's discourses and ideological hegemony. In Section 3, we saw the importance of contextualizing social problems by considering multiple factors. Looking at the work of philosophers of science and feminism, a common thread becomes clear: if we want to address a problem, we must consider its context. Regardless of whether the issue is scientific or more obviously social in nature, recognition of the multitude of factors that affect it is key.

Lewontin (1991) argues that one problem with the structure of the institution of science is that scientists think very narrowly when considering cause and effect. Scientists use the scientific method to isolate specific variables and understand their relationship, but this structure and approach offers a confined view of the whole picture because science and its practitioners operate within a very specific institution with particular discourses and ideological frames. The difficulty with such a narrow scope of vision is that it isolates variables and locates ills within specific individuals, or microcosmic units of analysis. There is no vision of the bigger picture, of the structural systems that are in place which hinder deep analysis or critical connections. Scientific discourse shapes a particular kind of research that legitimizes and reinforces existing ideological hegemony, the hegemony that feminism seeks to dismantle. As Sandra Harding (1991) argues, “whoever gets to define what counts as a scientific problem also gets a powerful role in shaping the picture of the world that results from scientific research” (p. 40). We then become embedded in a regime of truth. Feminist pedagogy questions, reveals, and challenges these regimes of truth. The feminist classroom is constantly changing, as it reacts to a society that is constantly changing.

In order to give students the opportunity to develop the critical thinking skills necessary to develop scientific literacy, I propose introducing the idea of intersectionality alongside teaching that variables and cause and effect are the basis of scientific method. As we saw earlier, intersectionality acknowledges the multiplicity of factors that are at play when considering an issue. It looks at a person's experience as holistically as possible, rather than isolating particular variables, and brings the same holistic view to scientists and scientific discovery. Intersectionality also examines the ways in which individual or institutional standpoint and social location results from several elements. Intersectionality is a way of considering all of the factors that compose our political identities such as gender, race, ethnicity, class, social status, sexuality, ability, and age. Intersectionality is the practice of analyzing how mutually constitutive categories of identity shape one another. The term was originally used by Kimberlé Crenshaw to refer to how gender and oppression interact and how they affect Black women's lives, particularly relating to the United States anti-discrimination law that failed to protect Black women because the law distinguished gendered discrimination from racialized discrimination (Carastathis, 2008). Crenshaw noted in her study of discrimination in the workplace that Black women were discriminated on the basis of race and gender at the same time, rendering them invisible to legal concepts of discrimination. Similar marginalization has happened in American feminist movements, when women of color, members of the queer community, and working class women who were active in feminism ended up being pushed out of the spotlight. This bias was present in the movement from the beginning, and continued as the public face of feminism became dominated by white middle and upper class women who had the privilege of identifying with the whiteness of the men in power. This can also be seen in the history of science, a field typically dominated by men. Even when women gained access to study and perform science, it was largely for white women who were married to upper class white men. As Harding (1991) points out, "class and race opportunities are obviously related: poor women and women of color were as unlikely as *their* brothers to have relatives who were scientists" (p. 22).

The goal of recognizing intersectional aspects of an issue is to understand the systems of oppression that affect the issue in order to form strategies of resistance. Intersectionality attempts to reveal the factors that structure experiences of oppression in order to help us recognize that our experiences are interconnected and shared. Even if we do not share certain factors that inform our identity, we are still part of the same ideological hegemony. Intersectionality can seem abstract at first but when compared to the scientific idea of variables in experiments, it can be made quite concrete. As Lewontin argued, the scientific method often tests a particular, isolated variable. A new experiment can be performed to test another variable, or a "fact" can be proven by forging causation between correlated variables.

I would raise the topic of intersectionality at the beginning of the year, when introducing different methods of experimentation, and the risks of confusing causation with correlation. I would begin by discussing intersectionality, using moments when students felt misunderstood or silenced as examples. I might reference issues they have had with school administration, or their parents, especially involving curfew. For example, is Masha not allowed to go out late at night because she is a girl, because she is not of legal drinking age, or because she has Oppositional Defiant Disorder and her parents are afraid she won't be able to control herself and make what they consider to be rational decisions? A variety of variables are in play. I would then relate factors of intersectionality with variables of experiments.

This could relate to at least two lessons: the pitfalls of observational and controlled experiments (figure 1, see appendices), and the difference between correlation and causation (figure 2, see appendices). Just as it is important to acknowledge the multiplicity of factors that interrelate to inform a person's identity, it is important to consider all the variables of a study. Intersectionality provides a solid foundation to start a science course for a variety of reasons. For one, it sets a personalized tone. It shows that I am aware of some of the issues students face in their personal lives, and demonstrates how the personal does have a place in the science classroom. It places importance on multiple ways of knowing and gives voice to personal experience. For another, it teaches the concepts of correlation vs causation, and intersectionality, which are abstract and difficult to grasp, but both absolutely necessary in an understanding of scientific literacy. By teaching these concepts at the start of the year, I am equipping students with the basic skills to approach the rest of the year.

Critics

Critics could argue that this approach will add to the ever expanding list of material to cover and tasks for teachers to execute. There can be a worry that this approach will be too time consuming, taking away from time that could otherwise be spent covering the required material. However, it is worth noting that my suggested approach is a matter of changed perspective and alternative methodology, not necessarily a change or addition of material content itself. Considering a critical approach to Science and Technology is a difference in instruction, which is not necessarily a matter of course content. The theory of relativity will remain in the course; it is how we teach about it that I want to change.

A Varied Approach

It is also worth noting that while I have found critical theory and feminism to be vitally instrumental to my practice as a teacher, my approach is but one of many. I have found it effective for me and my students and I have shared these ideas in the hopes that they might inform or be useful to other teachers who are having difficulty with the ubiquitous requirement of the Ministry to teach critical thinking. However, I encourage fellow teachers to pick and chose aspects that speak to them, and that they deem useful for them and their students. Theory only becomes alive when put into practice, and the success of a practice is its relevance to the users.

Conclusion

In first wave feminism, liberal feminists emphasized how to bring women “into” science. It highlighted the ways women were discouraged from entering sciences, and led to the creation of programs and opportunities to get more female students in the field. Second wave feminism aimed for gender-inclusive science. It challenged the nature of science and scientific knowledge by arguing that value-free science does not exist and pointed out that ways of knowing and relating are gendered. Second wave feminists therefore fought to have multiple ways of knowing incorporated, and for science to be more gender-inclusive. Finally, third wave feminism emphasized the notion of situated knowing and learning. It pointed out that first and second wave feminism essentialized what it meant to be female or male, and instead proposed an intersectional lens to analyze gender, race, and class. This self-reflexivity challenged scientific truth regimes by analyzing how science is situated as a school subject, but also by situating the role of teachers and students in the educational process.

Whether we are considering Roth and Desautels' (2002) approach to scientific literacy or feminists' approach to gender inclusion and self-reflexivity, the message is clear: science must be inclusive of the complex intersections of learner's identities so that students may participate and engage in their education, and ultimately be empowered to better participate in a society increasingly influenced by Science and Technology.

Conclusion

The Quebec Education Plan lists exercising critical judgment as a competency for secondary school education. In Science and Technology, students are expected to “learn to question their opinions and positions and analyze the values underlying them. They become aware of the influences to which they are exposed" (Ministère de l’Éducation, 2004, p. 41) and we as educators are expected to help students examine issues, and evaluate facts (Ministère de l’Éducation, 2004, p. 40). But as a teacher trained in Quebec, I found there was little direction about how to do this. Upon further research into philosophy of science education and critical pedagogy, I discovered the work of R.C. Lewontin, who argued that science as a practice itself is not as value neutral as it purports.

In Section 1: Theory in a Nutshell, I give a summary of ideas to address how we ourselves, as teachers, can learn to question opinions, positions, and their underlying values. I discuss critical pedagogy approaches (Freire, 1970, 2013; hooks, 2000) that treat students as dynamic learners, not just empty vessels. I introduce the notion of discourse (Hall, 1992) and its relation to upholding ideological hegemony (Gramsci, 1971). Using this framework, I discuss Lewontin's (1991) perspective of science: a triumphal, religion-like, subjective activity that often functions as a social legitimizer.

In Section 2: Textbook Analysis, I investigate if these theoretical perspectives are actually taking place in textbooks. I do a quantitative and qualitative analysis of *Eureka* and *Connection* and find a mass of facts that are value-ridden, and inauthentic activities that do not encourage active participation or critical thinking. In order to address this problem, I look solutions proposed by scholars in science education in Section 3.

In Section 3: Theory in Practice, I give an overview of feminist movements and how they have affected education and specifically, science class. I specifically highlight the importance of self-reflexivity and gender inclusivity in the classroom. I also discuss the merits of teaching scientific literacy over the traditional version of science for scientists.

If we want to teach our students critical judgment, it is important that we as teachers exercise such judgment ourselves. In researching critical pedagogy, philosophy of science, and intersection of these fields with the Quebec science curriculum, I hope to provide teachers with an alternative, critical, framework for our practice.

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Appendices

Figure 1

Observational vs Controlled Experiments

There are many types of experiments. Two types of experiments are **observational** and **controlled**. The difference between observational and controlled experiments is whether or not the scientist can manipulate the variable being studied. Remember that experiments have:

a treated group: the subject being studied/manipulated.
a control group: the "normal" group that the treated group is compared against
variables: what is being changed in order to test the hypothesis

Observational Experiments
Definition
In **observational experiments**, the scientist develops a theory based on their observation of particular variables. All types of experiments require observation, but "observational experiment" refers to a specific type of experiment. "Observational experiment" means that the assignment of subjects in the treated group and control group is beyond the selection of the scientist. The subjects belonging to the treated group and control group are divided based on variables that existed before the experiment.

Example:
There is a hypothesis that women who receive abortions are more likely to develop breast cancer than women who do not receive abortions.

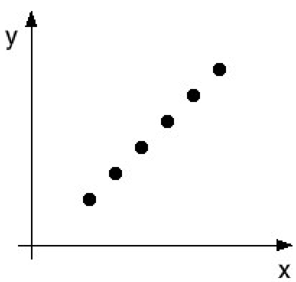
Hypothesis: women who have abortions are more likely to develop breast cancer than women who have not had abortions
Treated group: women who have had abortions
Control group: women who have not have abortions
Variable being studied: abortion
To test this hypothesis, a scientist cannot assign who belongs to the treated group and who belongs to the control group. The women in this experiment either had or did not have abortions before the study began. That means the doctor did not abort women's babies purposely for the study.

Figure 2

Correlation and Causation
"Correlation does not imply causation" is a popular phrase used in science and the analysis of statistical data. Just because two things happen at the same time doesn't mean one necessarily caused the other.

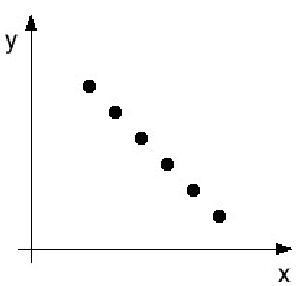
Correlation
Correlation indicates the strength and direction of a linear relationship between two variables. Correlation means association.

Positive Correlation



As the value of X increases, the value of Y increases.
Increase in one variable is associated with the increase of the other
For example:

Negative correlation



As the value of X increases, the value of Y decreases
Increase in one variable is associated with the decrease in the other
For example:

Causation

Causality refers to the relationship between two events. In a causal relationship, one event is said to be the direct consequence of the other.
For example:

Correlation does Not Imply Causation

Correlation does not always imply causation because one, or a combination of, the theories below is present:

1. Reverse causation: the second variable might actually influence the first variable

2. Third factor: a third variable that has not been measured in the experiment might be directly influencing the other variables

3. Coincidence: the possibility that two variables that occur at the same time are entirely unrelated to each other. They do not in fact affect each other.

Reason:
Observational experiments often involve people, and people cannot be tested on the same way a non living object can. There are many reasons why an experiment would be observational. Some reasons include:

1. Ethical Standards: It would be unethical for a scientist to impose certain variables, especially when studying variables that effect people. If scientists want to study the survival rate of car crash victims at a certain speed before impact, the scientist would have to form theories based on the survival rate of people who have already been in crashes. It would be unethical for a scientist to force people to have car crashes at different speeds.

2. Laws: Certain variables would be illegal to impose on people. Imagine that a scientist wants to study public health effects of a community-wide ban on smoking in public indoor areas. The scientist cannot go into a community and ban smoking for the purpose of their study because scientists have to respect the law of each community. The scientist would have to study the health effects in communities that already have smoking bans, and compare them to health effects in communities that do not have smoking bans.

3. Practicality: Sometimes it is difficult to find enough subjects with the variable being studied. Suppose a scientist wants to study the possibility that a certain medication (500mg of Illnadamine) is causing a particular side effect (headaches). The scientist would have to study people who already have headaches who have taken the Illnadamine. He cannot purposely give people a medication they don’t need just to see if they end up having headaches.

Controlled Experiments
Definition:

In a controlled experiment, scientists induce the variables that determine whether or not a subject is part of the treatment group or the control group.

Example:
Imagine that a scientist wants to prove that sunflowers turn to face where the sun is in the sky.

hypothesis: the sunflower plant will turn to face the sun throughout the day
subject: sunflower
treatment group: sunflowers in the sun
control group: sunflowers kept in absolute darkness
variable: amount of sun the sunflower is being exposed to

In this experiment, the scientist can control which plants belong in which group. The scientist gets to manipulate the amount of sun the flower is being exposed to.