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Towards a Philosophically and a Pedagogically Reasonable
Nature of Science Curriculum

by

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This work is dedicated to my parents

Jirair and Yevnige Yacoubian

Abstract

This study, primarily theoretical in nature, explores a philosophically and pedagogically reasonable way of addressing nature of science (NOS) in school science. NOS encompasses what science is and how scientific knowledge develops. I critically evaluate consensus frameworks of NOS in school science, which converge contentious philosophical viewpoints into general NOS-related ideas. I argue that they (1) lack clarity in terms of how NOS-related ideas could be applied for various ends, (2) portray a distorted image of the substantive content of NOS and the process of its development, and (3) lack a developmental trajectory for how to address NOS at different grade levels. As a remedy to these problems, I envision a NOS curriculum that (1) explicates and targets both NOS as an educational end and NOS as a means for socioscientific decision making, (2) has critical thinking as its foundational pillar, and (3) provides a developmental pathway for NOS learning using critical thinking as a progression unit. Next, I illustrate a framework for addressing NOS in school science referred to as the critical thinking - nature of science (CT-NOS) framework. This framework brings together the first two of the three elements envisioned in the NOS curriculum. I address the third element by situating the CT-NOS framework in a developmental context, borrowing from the literature on learning progressions in science and using critical thinking as a progression unit. Finally, I present an empirical study of experienced secondary science teachers' views of a NOS lesson prepared using the CT-NOS framework. The teachers attended a professional development workshop at which the lesson, and the characteristics of

the CT-NOS framework, were presented. The analysis of the qualitative data revealed that most teachers found the lesson to be somewhat feasible for a secondary science classroom, useful or somewhat useful to their students, and interesting. The teachers focused on 14 features of the lesson in their judgments and recommendations. The study revealed a number of teacher challenges generally related to critical thinking and its teaching as well as to the distinction between critical thinking about NOS and critical thinking with NOS.

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Chapter 1

Introduction

Research Area

Many science education scholars and policy documents consider scientific literacy to be a major goal of science education (American Association for the Advancement of Science [AAAS], 1993; Bybee & DeBoer, 1994; Council of Ministers of Education Canada [CMEC], 1997; Holman 1997; Kolstø, 2001a; Laugksch, 2000). The literature is rich with lists of attributes that citizens need to possess in order to be considered scientifically literate (e.g., Arons, 1983; Bybee, McCrae, & Laurie, 2009; DeBoer, 2000; Eisenhart, Finkel, & Marion, 1996; Hurd, 1998). In recent years, the Programme for International Student Assessment (PISA) of the Organization of Economic Cooperation and Development (OECD) assessed students' scientific literacy rather than their understanding of science content (OECD, 2003, 2006). This research focuses on one of the central aspects of scientific literacy, conceptualized as nature of science (NOS), which involves developing informed understandings *about* science. NOS refers to the epistemology of science, science as a way of knowing, and the values and beliefs inherent to scientific knowledge and its development (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992).

Although there are several reasons why science educators endorse the existence of NOS in school science (Matthews, 1994), a number of these educators have highlighted the importance of NOS in formal science education settings as a means for developing scientifically literate individuals (e.g., Abd-El-

Khalick, Bell, & Lederman, 1998; Bell & Lederman, 2003; Carey & Smith, 1993; Khishfe, 2008; Lederman, 1999, 2004; Schwartz, Lederman, & Crawford, 2004). Others have interpreted scientific literacy specifically from a perspective of decision making and have argued that having informed views of NOS would support citizens in decision making on socioscientific issues (Kolstø, 2001a; Zeidler, Walker, Ackett, & Simons, 2002). Driver, Leach, Millar, and Scott (1996) and Millar (1996) have gone further, associating NOS with building ideal democratic societies.

Many recent science education policy and curriculum documents have approached NOS from a similar perspective. In Canada, the Pan Canadian Protocol for Collaboration on School Curriculum (CMEC, 1997) has set forth four foundational pillars for a national science framework with the purpose of promoting scientific literacy in the country. Among these pillars, science, technology, society and environment (STSE), of which NOS is considered one dimension, is referred to as the driving force behind the framework. In the United States, the National Science Education Standards (NSES) (National Research Council [NRC], 1996), *the Benchmarks for Science Literacy* and *Project 2061* (American Association for the Advancement of Science [AAAS], 1993) agree that emphasis needs to be placed on overarching themes, such as scientific inquiry and NOS, rather than on teaching isolated scientific concepts. There is a similar focus on the significance of NOS in the new conceptual framework for K-12 science education (NRC, 2012).The conceptual framework states:

> Science has been enormously successful in extending humanity's knowledge of the world and, indeed transforming it. Understanding how science has achieved this success and the techniques that it uses is an essential part of any science education. Although there is no universal agreement about teaching the nature of science, there is a strong consensus about characteristics of the scientific enterprise that should be understood by the educated citizen. (NRC, 2012, p. 78)

In Europe, the concern for preparing citizens who can contribute to democratic decision making by taking informed choices is a highlight of the *White Paper on Education and Training* (European Commission, 1995). The document emphasizes the need for citizens to possess certain "scientific awareness" (p. 11) that will enable them to make informed choices on environmental and ethical issues. According to the document, "scientific awareness" encompasses an understanding of how science functions rather than scientific content knowledge, as is evident in the following statement:

> Clearly this [scientific awareness] does not mean turning everyone into a scientific expert, but enabling them to fulfil an enlightened role in making choices which affect their environment and to understand in broad terms the social implications of debates between experts. (European Commission, 1995, p. 11)

It is in the context of scientific literacy in general, and socioscientific decision making in particular, that the present study will attempt to look at NOS in school science. The term *socioscientific decision making* in this study is defined quite broadly to encompass decision making on any science-based or technology-based social issue that has a controversial and/or an ill-defined nature. Examples of such issues include whether legislation should be passed that would make cigarette smoking illegal (Bell & Lederman, 2003), whether animals should be used for research (Zeidler, Walker, Ackett, & Simons, 2002), whether genetically modified golden rice used for treating vitamin A deficiency should be produced and marketed (Khishfe, 2012), and whether global warming is caused by human activities or is a natural event posing no threat to the environment (Sadler, Chambers, & Zeidler, 2004).

Research Problem

The philosophical debates on what science is and how scientific knowledge develops have been existent for some time, yet these debates have taken on new dimensions during the last few decades. Matthews (1998) considers the older debates "domestic" (p. 162) in nature. Despite disagreements over the nature and purpose of science, there was a general agreement on the universality and disinterestedness of science. Matthews writes:

> There was general agreement that science was a good thing, that it was a cognitive enterprise abiding by intellectual standards, that it valued objectivity, that it sought to find truths about the world, and that it gave us the best possible understanding of nature and reality. (Matthews, 1998, p. 162)

The philosophical debates, however, took a different focus during the second half of the twentieth century. Kuhn's (1970) account of science gained popularity, and new traditions of explaining science emerged under the umbrella of the philosophy of science. Loving (1997) considers Kuhn's work revolutionary as it opened the path for "contextualist" or "relativist" traditions with various degrees of commitment to nonformalist views. Many scholars found the epistemological relativism in Kuhn's (1970) work quite appealing for justifying particular views of science and of how scientific knowledge develops. The traditional philosophy of science, with its commitment to a universal epistemology, was challenged by relative and contextual viewpoints in which, as Giere (1988) points out, sociological processes were seen to play an important role in the justification of knowledge claims.

The schism on such fundamental issues of science has since appeared in science education circles. The debates on NOS that are prevalent today in the science education community are quite contentious, often resulting in widely divergent viewpoints. A few examples of the questions raised in these debates include whether the diverse local practices within and across scientific disciplines necessitate a move away from a universal conceptualization of NOS (Rudolph, 2000); whether multiculturalism on epistemic grounds could replace a universalist view of science education (Stanley & Brickhouse, 2001); and whether universalism and multiculturalism can coexist (Siegel, 1997). Although these debates are significant from a purely academic perspective, science education policy makers, practitioners and empirical researchers are left to make difficult choices of which views about NOS to address in school science.

Given the contentious nature of the philosophical debates, many science curriculum documents and science educators highlight NOS-related ideas that form a common denominator among the different philosophical viewpoints. In this dissertation, I use the term *consensus frameworks* to describe frameworks for addressing NOS in school science that converge contentious philosophical debates into sets of NOS-related ideas that supposedly (1) reflect some level of generality of the characteristics of science, (2) show some level of consensus among various philosophical positions, and (3) invite learners to develop understandings about these ideas. During the last two decades or so, research conducted by Lederman and his collaborators involving consensus views of NOS has been quite influential in the science education literature and the term *consensus* is used quite widely in the context of that research agenda. In the following paragraphs, I provide examples of curriculum documents and scholarly research that involve the use of consensus frameworks of NOS.

As a first example, Grade 9-12 students in the US, according to the NSES (NRC, 1996) document, should be able to develop understandings of the following NOS-related ideas among others:

> Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society. (NRC, 1996, p. 201)
>
> Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical

> arguments, and skepticism, as scientists strive for the best possible explanations about the natural world. (NRC, 1996, p. 201)

As another example, in Alberta, Canada, students in Grades 7, 8 and 9 are expected to develop understandings of a list of NOS-related ideas and skills. An example of these ideas is the following:

> Scientific knowledge is subject to change as new evidence is gathered and new interpretations of data are made. (Alberta Learning, 2003, p. 7)

Many science educators have developed and justified the use of similar lists of NOS-related ideas to be addressed in school science. Lederman and his research group, for instance, have developed a list of seven general aspects of NOS on which there is some agreement among philosophers, sociologists, historians of science and science educators (Lederman, 2004). Among these are the view that there is a distinction between observations and inferences; the view that scientific theories and laws differ; the idea that science is embedded in social and cultural contexts; the notions that scientific knowledge is tentative, empirical and subjective; and the idea that science involves human inference, creativity and imagination. Such a consensus is thought to present a common denominator among the various competing viewpoints. Along the same lines, Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) have provided empirical evidence of what the expert community of scientists, philosophers, historians, science educators, science communicators, and sociologists of science think are important general aspects of NOS that should be addressed in K-12 science education.

Consensus frameworks of NOS in school science have gained some positive attention in research studies that aim at guiding learners to develop their understandings of NOS (e.g., Akerson & Hanuscin, 2007; Bell, Blair, Crawford, & Lederman, 2003; Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). I believe, however, that there are at least three challenges associated with using consensus frameworks of NOS in school science. I elaborate these challenges in more depth and with examples in the coming chapters. Here I present just an overview of them.

First, these frameworks of NOS in school science lack clarity in terms of how the NOS-related ideas could be applied for various ends. The frameworks target *NOS as an educational end* and assume that when learners develop adequate understandings of NOS-related ideas, they are able to apply those understandings in various contexts. When socioscientific decision making is regarded as an educational end, the frameworks provide little support for the science teacher to guide their learners to make connections between their NOS understandings and decisions regarding socioscientific issues. In other words, these frameworks do not facilitate *NOS as a means for other educational ends.* If socioscientific decision making is an important outcome of science education in general and NOS instruction in particular, then it is imperative that NOS in school science provide opportunities for students to practice using their NOS understandings to make decisions on socioscientific issues. It is important to address *NOS as a means for socioscientific decision making* in addition to addressing *NOS as an educational end*. Walker and Zeidler (2007) argue for and propose developing a socioscientific issues approach to exploring aspects of NOS so that students not only develop their NOS understandings but also apply them within a context of decision making. There is emerging evidence that supports the plausibility of such a proposal (Khishfe, 2012).

Second, consensus frameworks of NOS in school science present a non-authentic image of the substantive content of NOS and the process of its development. Many science educators argue that K-12 science education should target only the teaching of general aspects of NOS on which there is some consensus among philosophers of science (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick et al., 1998; Khishfe & Abd-El-Khalick, 2002; Lederman, 2004). This approach fails to capture the diverse philosophical discourse and the competing viewpoints on NOS in an authentic way. The consensus frameworks are based on *apparent* rather than real consensus – an agreement that is restricted to surface level. As such they provide an unintentional message to learners that there is consensus among philosophers of science on the substantive content of NOS. Because convergence is often the main mechanism that has led science educators to derive NOS-related ideas for school science, they may convey the latent and undesirable message that convergence is a characteristic of the process by which the substantive content of NOS develops in philosophy. Even if we agree that convergence is emphasized only for pedagogical purposes, there is still little attention paid to how that convergence is reached or sought. The NOS-related ideas, rather than the process of their development, are in the foreground.

Therefore, more emphasis is placed on the substantive content of NOS and less on critical thinking – the process by which the substantive content of NOS develops.

Finally, consensus frameworks of NOS in school science are not sensitive to the developmental needs and cognitive levels of learners. The NOS-related ideas are not embedded in developmentally appropriate pedagogical pathways. Science educators address similar NOS-related ideas in the same fashion across levels from K-12 to teacher education programs. All or a combination of the same NOS-related ideas that we find in these frameworks are used to teach middle school students (Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010), secondary students (Bell, et al, 2003), pre-service science teachers (Schwartz et al., 2004), and in-service science teachers (Akerson & Hanuscin, 2007).

Perhaps the idea of replacing the NOS-related *ideas* with a NOS *curriculum* might be worth considering. My use of the term curriculum here is quite broad and pragmatic. Walker (2003) has defined curriculum as “a particular way of ordering content and purposes for teaching and learning in schools” (p. 4). My assumption is that a NOS curriculum would be an effective way of delineating and bringing together the following:

1. *What* to address under the title of NOS – A NOS curriculum would create a space for the substantive content of NOS and the process of its development (critical thinking) to coexist in a more authentic way.

2. *Why* to address NOS in school science – A NOS curriculum would better explicate and target NOS as an educational end and NOS as a means for socioscientific decision making.

3. *How* to organize what needs to be addressed under NOS – A NOS curriculum with *critical thinking* as a foundational pillar would organize the learning outcomes of NOS in school science and place them across a developmental trajectory. According to Ennis (1989, 1996a), critical thinking is a process the goal of which is to produce reasonable and reflective decisions on what to believe or do and which encompasses certain dispositions and abilities.

Motivation

Science educators who raise questions on the *desirability* of educational outcomes often engage in philosophical inquiry in attempting to answer their questions. The primary target audience for these science educators is composed of philosophers or science education researchers rather than curriculum designers or practitioners. As a result, these scholars often shed minimal light on the practical consequences of their ideas (e.g., Matthews, 1998; Norris & Korpan, 2000). Even when practical recommendations do exist in their papers, they are mostly written in terms that could not *directly* inform the science curriculum. Such an approach is not surprising, especially when the primary intentions of these scholars are taken into account. I consider here Matthews' (1998) as well as Norris and Korpan's (2000) papers as examples to illustrate my points.

Matthews engages in philosophical inquiry to argue against constructivists' proposals of NOS teaching. He reserves a few paragraphs at the end of his essay to raise classroom implications. Obviously, such implications do not constitute his primary objective in this paper. He writes:

> At a most basic level any text or scientific discussion will contain terms such as *law, theory, model, explanation, cause, truth, knowledge, hypothesis, confirmation, observation, evidence, idealization, time, space, fields,* and *species.* . . A professional teacher should be able to elaborate a little on these matters. . . Philosophy begins when students and teachers slow down the science lesson and ask what the above terms mean and what the conditions are for their correct use. (Matthews, 1998, pp. 168-169)

Along the same lines, Norris and Korpan engage in a philosophical inquiry to differentiate between the substantive content of science as *first-order statements* and NOS as *second-order statements* while showing instances where these statements might be in conflict. We find at the end of their essay a few pages devoted to educational implications. The scholars propose “simultaneously teaching the substantive content of science and respecting a plurality of ideas” (p. 240) so that students are guided to understand and respect the role of reasons and are encouraged to look for coherent views of their own.

Both Matthews’ and Norris and Korpan’s recommendations are significant and would be interesting places to start when thinking about alternative ways of addressing NOS in school science. In fact, both recommendations entail respecting the multiple views of NOS that are out there, despite the fact that each of the papers criticizes certain views and advances an alternative. Moreover, both papers highlight the importance of critical thinking as a requisite for learners in developing understandings of NOS, and as such both implicitly seem to discourage having pre-determined NOS-related ideas as learning outcomes. Indeed Matthews highlights the importance of searching for meanings of terms that are quite loaded while Norris and Korpan emphasize the role of critical thinking, specifically providing reasons and making coherent arguments. Building on these recommendations might potentially lead to addressing part of the problems of NOS in school science that I set forth earlier.

Nonetheless, if the recommendations set forth by Matthews and Norris and Korpan are to have the potential of informing curriculum and instruction, intermediary level work is needed in order to make these recommendations less abstract. Accordingly, there is the need to provide a *curricular emphasis* for these recommendations. In other words, making *curriculum* the central focus of inquiry might lead us into determining desirable ways of addressing NOS in school science. A curricular emphasis would better clarify what, why and how to address NOS in school science.

Taylor and Swinbank (2007, 2011) report on the design of an AS level course in the UK on the history, philosophy and ethics of science. The course promotes discussion, debates and research with the purpose of helping 16 to19-year-old students think critically about historical, philosophical and ethical issues raised by science. The course places a significant emphasis on the importance of developing certain thinking skills while engaging students in learning about science, and places less emphasis on the substantive content of NOS.

Taylor and Swinbank (2007) report that the course employs a very simple model for argument analysis that involves guiding the learners to distinguish between a point of view and reasons given for it, as well as to identify arguments and counter-arguments. Once proficient, learners apply the skills that they have learned to build a philosophical defense of their point of view on a research question of their choice. Hand and Levinson (2011) used questionnaires, interviews and classroom observations to evaluate the innovative features of this course. The researchers reported that the discussions in this course were enhanced significantly when the participants were equipped with the ability to analyze and evaluate arguments and when they had the necessary background information on the topic.

The AS level course on NOS in the UK emphasizes explicit instruction of both NOS and certain argumentation skills; moreover, the course encourages students to apply what they have learned and engage in authentic research. Khishfe (2012) utilized a similar approach in her study when exploring the relationship between NOS instruction and decision making on genetically modified food. Despite the fact that Khishfe relied upon a consensus framework of NOS in her study, she had to resort to argumentation research to identify resources to guide learners to apply their NOS understandings in socioscientific decision making.

Although there is some documented literature on the benefits of explicit teaching of argumentation in the science classroom (Jiménez-Aleixandre, 2008; Osborne, Erduran, & Simon, 2004; Zohar & Nemet, 2002), relatively fewer research reports exist on explicit teaching of both NOS and argumentation (McDonald, 2010; Walker & Zeidler, 2007). Khishfe's report adds to the literature in the sense that in her research students were provided with not only explicit instruction in both NOS and argumentation but also explicit guidance in how to apply their NOS understandings in socioscientific decision making. Similar to the AS level course on NOS (Taylor & Swinbank, 2007, 2011), Khishfe's explicit instruction of argumentation involved teaching the students how to formulate arguments, counterarguments and rebuttals. It also stressed the importance of using evidence in backing up arguments.

There is a need to define more clearly *criteria* that students are taught as part of argumentation instruction. Delineating knowledge, skills and dispositions needed in argument formulation and argument evaluation as well as understanding how students learn this set of knowledge, skills and dispositions would be important contributions. As learners are explicitly taught to apply their NOS understandings in making decisions on socioscientific issues, they need to learn the criteria that could help them formulate and evaluate arguments.

Jiménez-Aleixandre and Erduran (2008) propose five potential contributions of argumentation in the science classrooms. One of these involves the development of critical thinking among students. Ennis (1989, 1996a) defines critical thinking as a "reasonable reflective thinking focused on deciding what to believe or do" (1989, p. 4). The relationship between critical thinking and argumentation is described by Ennis (1996a) in terms of the latter being a subordinate concept under critical thinking. With the purpose of providing students with a more comprehensive training in critical thinking about NOS and with NOS, the argumentation skills in both Khishfe's (2012) work as well as the AS level course on NOS in the UK (Taylor & Swinbank, 2007, 2011) could be situated in a framework of critical thinking. Argument development and evaluation are concepts of critical thinking (Ennis, 1996a) and the students could also be guided to learn other aspects of critical thinking that would contribute to their decision making. Ennis (1996a) has operationalized critical thinking into a set of concepts and has also delineated several criteria for each of those concepts (see Appendix A). Ennis's (1996a) critical thinking concepts and criteria could be valuable resources when instructing students to engage in developing their NOS understandings as well as applying them – whether they are engaged in authentic research (as in the AS level course) or in making decisions about a socioscientific issue (as in Khishfe's study). Moreover, the criteria could help educators to think about argumentation in developmental terms, and to develop learning progressions based on how students' understandings of the concepts of critical thinking develop.

From another perspective, a critical thinking framework could also be helpful in developing NOS understandings across several scientific contexts. There is some evidence that students' understanding of NOS is context-specific. Dagher and BouJaoude (2005) explored how college students evaluated the scientific status of the evolutionary theory. The researchers reported five themes in the students' responses: evidence, certainty, experimentation, method of theory generation, and prediction. Even though students in their sample understood the tentative nature of science, highlighted the importance of evidence, and appreciated the power of scientific explanations and predictions, they did not contextualize their understandings in appreciating the evolutionary theory. Instead, the students used generic understandings of NOS, such as the idea that scientific theories are tentative, in an attempt to refute the evolutionary theory. The researchers argued that generic attributions concerning NOS are too general to capture the subtleties of the nature of various scientific disciplines. Similar findings were reported by Ryder, Leach, and Driver (1999) as well as Brickhouse, Dagher, Shipman, and Letts IV (2002). In both of these studies, students' understandings of NOS were found to change with content and were dependent on the specific scientific context. When NOS learning is embedded in a critical thinking framework, the thinking process rather than the generic NOS-related ideas becomes the primary focus, thus facilitating context-specific NOS teaching and learning.

Irzik and Nola (2011) and Nola and Irzik (2011) criticize the consensus view of NOS in school science for (1) portraying an overly narrow image of science, especially by excluding aims and methodological rules in science; (2) providing a uniform view of science and being insensitive to the differences among scientific disciplines; and (3) lacking systematic unity. They borrow from Wittgenstein's notion of family resemblance to present a picture of NOS for the purposes of science education. The researchers classify the characteristics of science under four categories: scientific activities, scientific aims and values, scientific methods and methodological rules, and scientific products. They provide examples of elements under each category and claim that while no two scientific disciplines share all of the elements under each category, they share enough of them to be classified as science. The substantive NOS content generated by these researchers is promising because "it is free of philosophical commitments such as realism, positivism, empiricism, constructivism and the like. One can adopt any of these, depending on how one wants to spell out each item that falls under each category of the family resemblance approach" (Irzik & Nola, 2011, pp. 604-605).

Nonetheless, given that Irzik and Nola focus on the substantive content of NOS as the primary goal of teaching NOS in school science, they have little to say about the skills and dispositions (and knowledge of these skills and dispositions) required of learners as they engage in learning about NOS. They mention that "such a characterization is only as good as the use it is put to" (Irzik & Nola, 2011, p. 605). Moreover, although they give some examples of how their approach could be used in classroom settings, the researchers do not place their framework across a developmental trajectory. There is no discussion of how students at different levels could be taught about NOS using the family resemblance approach.

As a final example to illustrate why I am motivated to conduct this research, Abd-El-Khalick (2012b) proposes keeping intact the NOS-related ideas present in currently available NOS frameworks, yet making sure to address them at increasing levels of depth across the curriculum. He writes:

> One viable alternative would be to continue to focus on a set of NOS aspects that currently are emphasized in reform documents and enjoy wide support within the science education community (tentative, empirical, inferential, creative, theory-laden, and social NOS, etc.). These aspects, however, would be addressed at increasing levels of depth as learners move along the educational ladder from elementary school to college-level science teacher education programs. Thus, treatment of the target NOS aspects would span a continuum from general, simple, and unproblematic in elementary grades to specific, complex, and problematized (or controversial) in science teacher education settings, while taking learners' developmental levels into consideration. (Abd-El-Khalick, 2012b, p. 1047)

In spite of the problematic nature of the NOS aspects in consensus frameworks, Abd-El-Khalick's proposal of placing those NOS aspects in a developmental context might contribute to more effective NOS teaching and learning. Yet, his approach might succumb to the fact that at a sophisticated level none of these NOS aspects enjoys a consensus, so they no longer can serve as elements in a consensus framework.

Purpose

The central purpose of my study is to explore an alternative way of addressing NOS in school science. I start by critically evaluating consensus frameworks of NOS in school science. As a solution to the problems thus identified, I envision a NOS curriculum that (1) explicates and targets both NOS as an educational end and NOS as a means for socioscientific decision making, (2) has critical thinking as its foundational pillar, and (3) provides a developmental pathway for NOS learning using critical thinking as a progression unit. The word *progression* is adopted from Duschl, Schweingruber, and Shouse (2007) and implies a gradual and successive development of more sophisticated understanding of and thinking about *critical thinking* as children learn about and investigate it during school years. The possibility of such a NOS curriculum might help advance new frameworks for NOS in school science that could have the potential of resolving some of the dilemmas faced by the science education community. Next, I study the possibility of one framework that I call CT-NOS (the acronym *CT* referring to *critical thinking* and *NOS* to *nature of science*). I examine the ways in which CT-NOS could change the focus of what is taught and learned under the title of NOS in school science. I also explore experienced secondary science teachers' views of a NOS lesson prepared using the CT-NOS framework. Consequently, the objectives of the present study are the following:

O1 To explore the potential of a NOS curriculum with particular characteristics (as outlined below in O2) as an alternative to consensus frameworks of NOS in school science

O2 To explore how NOS in school science could

1. explicate and target both NOS as an educational end and NOS as a means for socioscientific decision making
2. have critical thinking as a foundational pillar

3. provide a developmental pathway for NOS learning using critical thinking as a progression unit

O3 To synthesize a framework for addressing NOS in school science

O4 To explore developmental possibilities for the synthesized framework

O5 To explore experienced secondary science teachers' views of a lesson prepared using the synthesized framework

The present study will be delimited in various ways. First, despite its emphasis on a NOS curriculum, I do not intend to enter into ongoing debates on the nature of curriculum. My goal is to explore desirable ways of addressing NOS in school science. Entering into broad curriculum debates would remove the focus from that goal. Second, the purpose of the present study is envisioning a NOS curriculum with particular characteristics. I do not intend to develop a NOS curriculum that could be directly used for instructional purposes. Certain elements such as student assessment and use of language could be extremely important for a more comprehensive understanding of a NOS curriculum. They could be addressed in future projects but are beyond the scope of this study. Finally, I have explored experienced secondary science teachers' views of a lesson developed using the CT-NOS framework. It is important that the views of other stakeholders be studied in addition to those of teachers. Studying curriculum developers' and science textbook authors' views, to name just two, would have been equally valuable, and these would be useful projects to pursue in future.

Significance

The conclusions of the present study entail the replacement of the NOS-related ideas in science curricula with a NOS curriculum that (1) addresses both NOS as an educational end and NOS as a means for socioscientific decision making, (2) has critical thinking as its foundational pillar, and (3) provides a developmentally suitable pathway for NOS learning using critical thinking as a progression unit. To the best of my knowledge, a NOS curriculum with these characteristics does not exist. In particular, bringing together critical thinking and NOS and placing them in a developmental context are original investigations that could contribute to the field by stimulating further discussion among science educators, opening paths for new possibilities of empirical research and acting as a foundation to design NOS curricula.

Before proceeding with my critique of the consensus frameworks of NOS in school science, I will devote the last few pages of this chapter to a discussion of my method of inquiry and an overview of the coming chapters of this dissertation.

Method of Inquiry

The present study is mainly normative in nature. In exploring the potential of a NOS curriculum, I investigate *desirable* ways for addressing NOS in school science with the purpose of delineating potential ends for school NOS.

In recent years funding agencies employing evidence-based reform slogans, have attempted to shape educational research agendas. Oancea and Pring (2008) and Slavin (2008) have highlighted the ways in which evidence-based reform has contributed to making educational research central to educational policy. Oancea and Pring have argued that the highly publicized remarks of the Department for Education in the UK and clauses in the No Child Left Behind Act in the US have contributed to the search for "what works" and how "the subsequent transfer of such knowledge (deemed inherently cumulative) into practice and policy, was gradually pushed into the centre of publicly funded research in education" (p. 18).

Nonetheless, I believe that the field cannot move forward if educational research is limited to "what works". There is the need to constantly evaluate educational ends with the purpose of shaping and reshaping these ends. In his critique of evidence-based research and his argument that the latter should not be considered the only valuable form of research in education, Biesta (2007) writes:

> [E]vidence-based education seems to favor a technocratic model in which it is assumed that the only relevant research questions are questions about the effectiveness of educational means and techniques, forgetting among other things, that what counts as "effective" crucially depends on judgments about what is educationally desirable. (Biesta, 2007, p. 5)

Biesta goes even further to highlight a potential danger associated with limiting education to evidence-based research. He claims:

> Evidence-based practice assumes that the ends of professional action are given, and that the only relevant (professional and research) questions to be asked are about the most effective and efficient ways of achieving those ends. (Biesta, 2007, p. 8)

In taking such a stance, Biesta highlights the importance of a much broader goal of educational research and acknowledges that “education is a moral practice, rather than a technical or technological one” (p. 10) and that “the most important question for educational professionals is therefore *not* about the effectiveness of their actions but about the potential educational value of what they do” (p. 10). It is from such a perspective that the present study aims at exploring the potential of a NOS curriculum.

The present study involves theoretical research. One could trace such discourse throughout all volumes of the journal *Science & Education* published over almost two decades now and in other major science education journals. In this study I have investigated educationally desirable ends for NOS in school science. I have critically evaluated educational ends of NOS in school science that are currently espoused and have proposed alternative ends. The work advances a theoretical case that could generate potential empirical questions. Criteria that have guided my inquiry include: logical flow of ideas; critical evaluations of the existing research literature; support of arguments using reasons, justifications and examples; coherency; internal consistency; and consistency with current educational reforms.

The last section of this chapter provides an overview of the coming chapters of this dissertation. For each chapter I also highlight criteria that have guided my inquiry.

Overview

In Chapter 2, I start by presenting a critique of the consensus frameworks of NOS in school science. Chapter 2 is the foundation upon which subsequent chapters are built. I engage in a critical evaluation of relevant literature in science education and develop three arguments against consensus frameworks of NOS in school science. In brief, these arguments are that these frameworks (1) lack clarity in terms of how NOS-related ideas could be applied for various ends, (2) portray a distorted image of the substantive content of NOS and the process of its development, and (3) lack a developmental trajectory for how to address NOS at different grade levels. In developing my arguments I aim at providing reasons to justify them, and at doing so with coherency and internal consistency.

In Chapter 3, I build upon the three arguments developed in Chapter 2 to envision a NOS curriculum with particular characteristics. Particularly, I argue that a NOS curriculum needs to (1) address both NOS as an educational end and NOS as a means for socioscientific decision making, (2) have critical thinking as its foundational pillar, and (3) provide a developmental pathway for school NOS having critical thinking as a progression unit. In proposing the features of a NOS curriculum, I aim to support my conclusions with reasons, being consistent both internally as well as externally with current educational reforms, and being coherent. In addition to literature in science education, I also consult relevant literature in the philosophy of education and developmental psychology.

In Chapter 4, I present a framework for addressing NOS in school science referred to as the CT-NOS framework. The construction of this framework brings together two of the three elements envisioned in a NOS curriculum identified in Chapter 3. These elements are that a NOS curriculum needs to address NOS as an educational end and NOS as a means for socioscientific decision making, and that a NOS curriculum needs to have critical thinking as its foundational pillar. In order to accomplish my objective, I engage in (1) comparing, contrasting, critically evaluating and selecting a critical thinking theory; (2) exploring how the critical thinking theory chosen could be used to address both NOS as an educational end and NOS as a means for socioscientific decision making; and (3) studying the applicability of the framework through two examples.

In Chapter 5, I situate the CT-NOS framework in a developmental context using critical thinking as a progression unit. This outcome is consistent with my argument in Chapter 3 that a NOS curriculum needs to place NOS learning in a developmental pathway. I also aim at being consistent with current reform in science education, particularly by constructing my arguments in the context of learning progressions. I use literature in developmental psychology to advance an example that at least partly supports my case.

In Chapter 6, I present an empirical study that aims at determining experienced secondary science teachers' views of a lesson prepared using the CT-NOS framework. The teachers attended a professional development workshop that introduced the NOS lesson and the characteristics of the CT-NOS framework. I used open-ended questionnaires and follow-up interviews to collect qualitative data to elicit (1) feasible / useful / interesting features of the NOS lesson, (2) non-feasible / non-useful / non-interesting features of the NOS lesson, and (3) recommendations for improvement. I analyzed the data using Miles and Huberman's (1994) approach and discussed how the teachers' judgments and recommendations speak to my solutions to the three problems set forth in Chapter 3.

Finally, in Chapter 7, I provide an overall summary and conclusions of the study, discuss its contribution and limitations, and propose directions for future research.

Chapter 2

A Critique of the Consensus Frameworks of NOS in School Science

In this chapter I build on the three problems that I have outlined in Chapter 1, namely that the consensus frameworks (1) lack clarity in terms of how NOS-related ideas could be applied for various ends, (2) portray a distorted image of the substantive content of NOS and the process of its development, and (3) lack a developmental trajectory for how to address NOS at different levels.

Lack of Clarity in How NOS-Related Ideas Could be Applied for Various Ends

In this section I review the literature-based reasons for addressing NOS in school science. I show that as far as the NOS instruction is concerned, many science educators seek to develop learners' understandings of NOS and as such they emphasize *NOS as an educational end.* Nonetheless, many science education policy and curriculum documents highlight the importance of preparing citizens who can participate in democratic decision making. I argue that consensus frameworks of NOS do not explicate *how* future citizens could apply their NOS-related ideas for various ends. Particularly, these frameworks do not address *NOS as a means for socioscientific decision making.*

Before proceeding any further, a clarification of the ends-means distinction is needed here. *Ends* and *means* are relative terms and an understanding of the underlying context might be important in order to appreciate the use of these terms. An educational end in a particular context might be a means for another end in another context, and that end might be a means for yet a third end, and so on. In this dissertation, the phrase *NOS as an educational end* is used to refer to NOS instruction that has developing learners' understandings of NOS as a legitimate goal for its own sake, or to NOS instruction that targets developing learners' understandings of NOS but is not clear about how learners could apply those understandings for various ends. The phrase *NOS as a means for socioscientific decision making* is used to refer to NOS instruction that views learners' understandings of NOS as a means of achieving another educational end, namely socioscientific decision making.

There are a number of reasons for addressing NOS in school science. Matthews (1994) has set forth a number of ways in which the inclusion of history and philosophy of science could contribute to science education. Among the contributions that Matthews finds significant are (1) humanizing of the sciences and situating them in personal, ethical, cultural and political contexts; (2) promoting critical thinking; and (3) promoting a fuller understanding of the scientific content. Along the same lines, in their review of the literature dealing with the rationale for teaching NOS in school science, McComas, AlMazroa, and Clough (1998) found that science education researchers think that NOS enhances (1) learning of science content, (2) understanding of how science operates, (3) interest in science, (4) decision making, and (5) science teaching.

The inclusion of NOS in school science reflects the assumption that informed understandings of NOS are important for developing scientific literacy. In fact, a number of scholars consider NOS to be one aspect of scientific literacy.

Arons (1983) presents a list of what a scientifically literate individual should be able to do. Many items found on his list could be viewed as objectives related to developing understandings of NOS. For example, Arons thinks that a scientifically literate individual should "[u]nderstand the meaning of the term theory in the scientific domain" (p. 93) and "[u]nderstand, again through specific examples, the sense in which scientific concepts and theories are mutable and provisional rather than final and unalterable" (p. 93). Hurd's (1998) list of the characteristics of a scientifically literate person is similar to that of Arons (1983). Many items on Hurd's list are also related to acquiring understandings of NOS (e.g., "recognizes that science concepts, laws and theories are not rigid but essentially have an organic quality" [p. 413]). DeBoer's (2000) historical analysis of the goals of science education reveals that there have been nine distinct goals of science education that could be related to the broader goal of scientific literacy. A number of these goals are related to developing understandings of NOS (e.g., teaching and learning about science as a cultural force [goal 1], and science as a particular way of examining the natural world [goal 6]). Norris and Phillips (2003) have identified from the literature eleven different components of scientific literacy, among which several components are related to NOS: knowing what counts as science and how science differs from non-science, interdependence in learning science, understanding NOS, knowing the risks and benefits of science, and being able to think critically about science. Finally, in the area of assessment, Bybee, McCrae, and Laurie (2009) introduced the essential features of the scientific literacy component of PISA 2006. They argued that scientific literacy referred to certain features, one of which was related to students' ability to understand knowledge about science.

Many science education policy and curriculum documents as well as many intervention studies related to NOS instruction in school science have focused on *NOS as an educational end*. NOS is a category of the science content standards of the NSES in the United States (NRC, 1996). The NSES document targets NOS in several places as an educational end, as is evident in the section quoted below:

> In learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise. The standards for the history and nature of science recommend the use of history in school science programs to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures. (NRC, 1996, p. 107)

NOS is also addressed as an educational end in the Pan Canadian science curriculum (CMEC, 1997). The document states:

> Students will develop an understanding of the nature of science and technology, of the relationships between science and technology, and of the social and environmental contexts of science and technology. (CMEC, 1997, section 4)

The document highlights scientific literacy as a major goal of science education in Canada. It also emphasizes students developing understandings of NOS as an important aspect of scientific literacy under the foundation of science, technology, society and the environment (STSE). Yet, the document does not clarify *how* learners can apply their NOS understandings for the ultimate goal of scientific literacy.

In determining which aspects of NOS should constitute the list of NOS-related ideas in school science, Lederman (2004) claims that one criterion that has guided his research team has been the usefulness of that aspect for all citizens. Many science educators have used Lederman's seven aspects of NOS or a combination of them in intervention studies to improve learners' understandings of NOS. Most of these studies (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson, Buck, Donnelly, Narguand-Joshi, & Weiland, 2011; Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Kim & Irving, 2010; Paraskevopoulou & Koliopoulos, 2011) have addressed NOS as an educational end. In these studies learners were guided in developing their NOS understandings by engaging in activities that had explicit and reflective discussions of NOS as one component. For example, Akerson et al. (2000) engaged pre-service elementary teachers in learning activities that were coupled with explicit instruction of NOS at the beginning of an elementary science methods course. During the course, the learners were provided with further opportunities to reflect on their NOS views. Using pre- and post-instruction assessments, the researchers found that the learners made substantial gains in some of the NOS objectives that were targeted in the course.

Despite their focus on NOS as an educational end, many science curriculum and policy documents, and many empirical researchers, do not explain how NOS-related ideas could be applied to various other educational ends. In particular, they do not explicate how to address *NOS as a means for socioscientific decision making*. Consider the following example: There is some agreement that high school students need to develop understandings of the tentative aspect of NOS (e.g., Lederman, 2004; NRC, 1996). Developing understandings of the tentative aspect of NOS is considered to be a cognitive educational outcome (Khishfe & Abd-El-Khalick, 2002). Consequently, these frameworks target the development of students' understandings of the tentative aspect of NOS as an educational *end*. Now suppose that as future citizens these same students are to practice making decisions on a socioscienific issue – whether their school should give creationism equal weight to the theory of evolution in the science classroom. Consensus frameworks of NOS do not articulate how students would use or apply their understandings of the tentative aspect of NOS to make decisions on this or similar issues. They do not provide resources that could enable an educator to guide her learners, for instance, to analyze whether creationists' views of creation could ever be tentative and whether creationists could subject their claims to any revision. Had students been encouraged to use their understandings of the tentative aspect of NOS in reaching decisions about this or similar issues, their understandings would have served as a *means* in the process of decision making.

There is a broader reason for why scientific literacy is a highlight in science education policy and curriculum documents. Scientific literacy has been considered not only in contemporary science education literature, but also among government-sponsored funding organizations, scientific communities, and consumer advocacy agencies. The significance of scientific literacy resides in preparing future citizens who can make informed decisions as consumers (European Commission, 1995), understand the social implications of science-related debates among experts, and make informed decisions on science-related issues (Bell & Lederman, 2003; Carey & Smith, 1993).

Laugksch (2000) differentiates between the micro and the macro views of scientific literacy. While the micro view is related to the direct benefits of scientific literacy to the individual, the macro view is related to the benefits that such literacy has to the society. Laugksch highlights five main outcomes under the macro view as the advantages of having a scientifically literate society. A scientifically literate public, he writes, could (1) contribute to the economic well being of a nation, (2) provide greater support for science, (3) have more realistic expectations from science, (4) contribute to democratic decision making, and (5) provide benefits to the society at large because of the relationship that exists between science and culture.

From this perspective, if students are to be prepared so that as future citizens they could make informed decisions on socioscientific issues and contribute to democracy, they need to be guided towards that goal. It is not enough to address NOS as an educational end; NOS also needs to be addressed explicitly as a means of making decisions on socioscientific issues. In their democratic argument for promoting public understanding of science, Driver et al. (1996) consider NOS understanding important in order for citizens to understand science and technologically based issues and to be involved in the decision making process in a democratic society. Kolstø (2001a) proposes a general framework for analyzing socioscientific issues. His framework is based on eight "content-transcending topics" (p. 292) summarized under science as social process, critical attitude, and the limitations and values of science. Kolstø argues that these topics need to be included in the science curriculum if school science is to serve as "science for citizenship" (p. 291), or preparation for analyzing and making decisions of socioscientific issues. Obviously, Kolstø finds a connection between NOS understanding and the ability of citizens to make decisions on socioscientific issues in spite of not delineating explicitly *how* learners need to use the tools that he has proposed.

A number of science educators have attempted to study empirically the role of NOS understanding in socioscientific decision making (e.g., Bell & Lederman, 2003; Sadler & Zeidler, 2005; Zeidler et al., 2002). A more thorough review will be presented in the next chapter. A number of these studies have shown that participants did not necessarily use their NOS views in making decisions on socioscientific issues (e.g., Bell & Lederman, 2003). Nevertheless, many of these researchers have suggested that informed NOS views could have the potential for improving socioscientific decision making (Bell & Lederman, 2003; Khishfe, 2012; Zeidler et al., 2002).

In sum, learners need to be guided to make explicit links between their NOS understandings and the decisions that they make on socioscientific issues. It cannot be assumed that when we target NOS as an educational end and help students develop adequate NOS understandings that they will automatically be able to apply their NOS understandings and use them as a means for socioscientific decision making.

A Distorted Image of the Substantive Content of NOS and the Process of its Development

The main purpose of this section is to compare the philosophical discourse on NOS inside science education circles and within consensus frameworks of NOS in school science that have been popular in recent science education literature and curriculum documents. I first engage in a critical analysis of the philosophical discourse on NOS with the purpose of highlighting features that characterize this discourse. Next, I engage in critical evaluation of the consensus frameworks of NOS in school science. I use the features of the philosophical discourse identified in the first part as a basis to show that consensus frameworks of NOS portray a non-authentic image of the substantive content of NOS and the process of its development.

Philosophical discourse on NOS inside science education circles. In this section I focus on two specific areas of the philosophical debates on NOS inside science education, namely (1) the debates on the role of culture in science and the status of Western Science (e.g., Cobern & Loving, 2001; Siegel, 1997; Snively & Corsiglia, 2001; Stanley & Brickhouse, 2001) and (2) the debates on the existential status of scientific objects (e.g., Driver, Asoko, Leach, Mortimer, & Scott, 1994; Norris & Korpan, 2000; Staver, 1998). I review these debates while concurrently engaging in critical analysis with the purpose of highlighting certain features that characterize this discourse. I demonstrate that scholars involved in these debates (1) produce competing NOS-related ideas, (2) use critical thinking as a main mechanism for debating, (3) rely on critical thinking as the main tool for producing NOS-related ideas, and (4) as a group produce divergent recommendations on how to address NOS in school science.

On the role of culture in science and the status of Western Science. The question of whether science is a universal or a culture-specific endeavor has been raised by a number of scholars. Matthews (1994) provides quite a comprehensive explanation of epistemological universalism:

> Universalists regard science as an intellectual activity whose truth-finding goal is not, in principle, affected by national, class, racial or other differences; science transcends human differences. (Matthews, 1994, p. 182)

Such a definition of universalism does not rule out the role of culture. Indeed, Matthews argues that culture has an important role in shaping the work of scientists; nevertheless, he writes, cultural influences cannot determine the adequacy of scientific theories as "the material world ultimately judges the adequacy of our accounts of it" (Matthews, 1994, p. 182). He writes:

> Scientists propose, but ultimately, after debate, negotiation and all the rest, it is the world that disposes. The character of the natural world is unrelated to human interests, culture, race or sex. Ultimately, the concept is judged by the object, not the other way around. (Mathews, 1994, p. 182)

Such a conceptualization of universalism situates culture and its role outside epistemic grounds. Even though multiculturalism is a social fact, it could not act as an arbitrator for scientific knowledge and in that sense there could be no such thing as multicultural science. This position does not underestimate the significance of multiculturalism though, especially when referenced as a politics of recognition (Taylor 1994). Indeed, many scholars (e.g., Irzik & Irzik, 2002; Matthews, 1994; Siegel, 1997) argue that a multicultural science education cannot be justified on epistemic grounds but highlight the role of multiculturalism in science education in terms of showing respect to different cultures with an underlying presumption that all human cultures have an equal worth. These scholars do not find the universality of science and multiculturalism to be in conflict. In fact, Siegel makes a moral case for multiculturalism and acknowledges that science education should be both multicultural and universal.

Nonetheless, multiculturalism seems a problematic theory that has ambiguities and inner tensions (Irzik & Irzik, 2002) often connoting more than a single reference. In addition to being referred to as a politics of recognition, multiculturalism is also referred to as an epistemology (Stanley & Brickhouse, 2001). A number of scholars (e.g., Snively & Corsiglia, 2001; Stanley & Brickhouse, 2001) argue for epistemic multiculturalism and treat the latter as a better alternative to universalism. The debates between the two groups are quite polarized. In the paragraphs that follow I further elaborate the debate, focusing on the status of Western Science and concurrently highlighting certain features related to the debate.

Snively and Corsiglia (2001) as well as Stanley and Brickhouse (2001) defend a multiculturalist position for science and science education. Snively and Corsiglia argue that the definition of science should be broadened and that "Traditional Ecological Knowledge" (TEK) should be treated as science. Their objective is clear:

> In this article, we argue the view that since Aboriginal cultures have made significant contributions to science, then surely there are different ways of arriving at legitimate knowledge. Without knowledge, there can be no science. Thus, the definition of "science" should be broadened, thereby including TEK as science. (Snively & Corsiglia, 2001, p. 8)

Snively and Corsiglia's proposal of considering TEK as science does not intend to situate TEK under the umbrella of a universal science. The authors indeed set forth a relativistic position and unite their voice with Ogawa (1989) to claim that science is culture specific and that Western science is one specific form of science among many others. Along the same lines, Stanley and Brickhouse also argue against a universalist view of science. They explicate their objectives in the introductory section of their paper:

> We begin by summarizing the case for the universalist approach to science education. We then go on to challenge the arguments for epistemic and moral universalism used to defend a universalist conception of science education and argue for an alternative view of science as more "local" than universalist accounts allow. Following this discussion, we try to show how these different epistemological views would play out in terms of

decision-making about multicultural approaches to the science curriculum. (Stanley & Brickhouse, 2001, p. 36)

Both Snively and Corsiglia (2001) and Stanley and Brickhouse (2001) promise the reader, through the list of objectives that they have provided, that they will engage in critical thinking to "argue" for the contributions of Aboriginal cultures to science (Snively & Corsiglia, p. 8), "challenge" the arguments set forth by universalists, "argue" for an alternative position and "show how" decisions would be different in light of their proposal (Stanley & Brickhouse, p. 36). The use of these verbs indicates that the process of coming up with their positions will be explicated in their papers in addition to the positions themselves. Indeed they accomplish their promises. Snively and Corsiglia provide numerous examples to support their argument that Aboriginal cultures have contributed to science, and that science and science education should take into account the existence of different legitimate means of knowledge development. Stanley and Brickhouse criticize universalism and argue for the role of the human mind and culture in shaping knowledge claims. Accordingly, they set forth the following ideas as products of their critical thinking:

> 1) Our ability to understand nature is constrained by the limits of human cognitive abilities; 2) The observer is part of the reality that is observed, thus social construction plays a role in the scientific account of physical reality; 3) We cannot determine if reality is either uniform or invariant; reality may best be described as a flux; and 4) We can, however, make a case for the disunity of science (Harding, 1998), since the cognitive

> content of the sciences is shaped by culturally different forms and social organization of research. (Stanley & Brickhouse, 2001, p. 39)

Based on the ideas that they have argued for, the researchers then suggest that students be guided to develop cross-cultural perspectives. Accordingly, Snively and Corsiglia (2001) propose that students be guided to research several perspectives on a given topic or issue with the purpose of developing understanding of more than one theory for explaining the underlying phenomena. The researchers argue:

> Although the two perspectives may interpret the world differently, students should also see that the two overlap and can reinforce one another. Discussion should stress similarities as well as differences, areas where IK [Indigenous Knowledge] helps fill the gap where knowledge in WMS [Western Modern Science] is lacking, and vice versa. (Snively & Corsiglia, 2001, p. 28)

Stanley and Brickhouse (2001) suggest that students be exposed to "cross-cultural case studies" (p. 45) so that they develop an understanding of other cultural views of science as well as an understanding of the assumptions underlying Western Science. Both Snively and Corsiglia's (2001) and Stanley and Brickhouse's (2001) proposals focus on epistemological multiculturalism as a better alternative to universalism.

Cobern and Loving (2001), as well as Siegel (1997), take completely different stances on this issue than the scholars mentioned above. Both argue for a universal view of science. Cobern and Loving write:

> We will argue that good science explanations will always be universal even if we do incorporate indigenous knowledge as scientific and broaden what is taught as science. (Cobern & Loving, 2001, p. 51)

Siegel argues for a universal view of science as well as a universalistic morality, defending multiculturalism in universalistic moral terms. Siegel clearly states his main objectives in the abstract of his paper:

> In this paper, I first explore the reasons for embracing multiculturalism, arguing that multiculturalism is best conceived and defended in universalistic *moral*, rather than epistemic, terms. I then criticize the common view that multiculturalism is incompatible with a universalistic conception of science, and argue that multiculturalism is compatible with a suitably characterized epistemic universalism. (Siegel, 1997, abstract, p. 97)

Like Snively and Corsiglia as well as Stanley and Brickhouse, Cobern and Loving, as well as Siegel, explicate their critical thinking in their respective papers. Cobern and Loving promise to "argue" for universalism while Siegel promises to "explore reasons", "argue" and "criticize" with the purpose of setting forth their ideas. Based on their critical thinking about NOS, both set forth their respective positions.

Accordingly, Cobern and Loving question whether it is the universality of science or the intellectual exclusiveness that is problematic. They write:

> It seems to us that even if the definition of science were broadened to include what is now excluded, one would still have a "universal" science.

> Indeed, if there is no universal concept of science then how can anything be either included or excluded as science? (Cobern & Loving, 2001, p. 61)

The authors highlight scientism as a potential problem facing Indigenous Knowledge – the problem of how science is often used to dominate public spheres as if it were of higher value than other forms of knowledge. Cobern and Loving propose that Indigenous Knowledge be appreciated as a different kind of knowledge for its own merits and remain distinct as a form of thought.

Siegel, on the other hand, claims that embracing multiculturalism is a moral obligation rather than an epistemic one; hence, multiculturalist educational commitments within science education can be justified only in moral terms. He writes:

> First, there is the moral ideal of multiculturalism itself: the universal requirement, binding on all persons and cultures, that members of all cultures must, in science education, be treated justly, with respect, and in ways which do not marginalize or trivialize them, their cultures, or the views of the natural world endorsed by those cultures. Second there is the character of science and its underlying epistemology. Since these are both universal, science educators must reject the either/or dichotomy. (Siegel, 1997, p. 105)

Cobern and Loving's as well as Siegel's recommendations regarding how to handle other ways of knowing in the classroom are made through the lens of a universal science. Cobern and Loving suggest bringing Indigenous Knowledge into the science classroom and helping students to see how science can benefit from these other forms of knowledge. Such a proposal does not mean, however, that other ways of knowing need to be considered equally valid. Cobern and Loving are clear on the distinction between pluralism and relativism. For Siegel, treating other ways of knowing with respect "does not require that those ideas be treated as correct, or as correct as the scientific ideas of the dominant, hegemonic culture" (Siegel 1997, p. 101), and he argues that the science classroom should be an opportunity to expose non-Western students to Western Science.

Cobern and Loving's as well as Siegel's recommendations are indeed strikingly different from each other and from those of Snively and Corsiglia and Stanley and Brickhouse. One similarity across the four papers is related to the promises that the authors make to engage in critical thinking and how they accomplish their objectives. As shown earlier, critical thinking is a major tool that these authors use in their debates and in deriving their respective NOS-related ideas and classroom recommendations. In the next part I focus on another debate on the existential status of ontological entities (Driver et al., 1994; Matthews, 1998; Norris & Korpan, 2000; Staver, 1998). I use the debate as another example to illustrate philosophical debates on NOS inside science education, concurrently identifying features that characterize the discourse.

On the existential status of scientific objects. Whether the objects of science are creations of the human mind or exist independently of it has been an area of debate inside science education (Driver et al., 1994; Matthews, 1998; Norris & Korpan, 2000; Staver, 1998). In a very broad sense, two philosophies underlie this debate, namely realism and constructivism. Matthews (1998) provides an overview of the common grounds on NOS between realists and constructivists:

> They [realists] recognize that science is a human creation, that it is bound by historical circumstances, that it changes over time, that its theories are underdetermined by empirical evidence, that its knowledge claims are not absolute, that its methods and methodology change over time, that it necessarily deals in abstraction and idealizations, that it involves certain metaphysical positions, that its research agendas are affected by social interests and ideology, that its learning requires that children be attentive and intellectually engaged, and so on. (Matthews, 1998, p. 166)

Matthews claims that if these positions add up to constructivism, then everybody could be regarded as a constructivist. However, constructivism, as defined by Matthews, is an epistemological doctrine associated with postmodern and antirealist views of science. Indeed, Matthews claims that the differences become obvious at the next level. He writes:

> Realists believe that science aims to tell us about reality, not about our experiences; that its knowledge claims are evaluated by reference to the world, not by reference to their personal, social, or national unity; that scientific methodology is normative, and consequently distinctions can be made between good and bad science; that science is objective in the sense of being different from personal, inner experience; that science tries to identify and minimize the impact of noncognitive interests (political, religious, gender, class) in its development; that decision making in

> science has a central cognitive element and is not reducible to mere sociological considerations, and so on. (Matthews, 1998, p. 166)

Staver (1998) presents a case supporting constructivism. His main objectives are clear early on in his paper. He promises to "present a case to support [his] own and others' assertions that constructivism is a sound theory" and to "respond to constructivism's critics" (p. 501). Staver's use of the verbs "present" (a case) and "respond" indicates that he promises to explicate his critical thinking about the topic. Indeed, he fulfills his promise, and based on his critical thinking, he makes several claims in favor of constructivism. He considers the problems of truth and knowledge to be the ones that divide constructivists from their critics. Knowledge, that is the truth of sentences, statements and propositions, is viewed as an internally coherent system. Constructivism, to him, makes no presuppositions about the existence of a world independent of our perceptions. The observer and the observed are tied to each other. He takes a strong stand against realism and universalism in this regard. He writes:

> The practice of science does not change when one rejects truth as correspondence and embraces truth as internal coherence. Only the wishes of science change. Science should give up the hot pursuit of the independence, discovery, lawfulness, and certainty of nature via the correspondence theory of truth. (Staver, 1998, pp. 516-517)

He continues:

> Free of ontology and the root paradox, science in a constructivist perspective is also free of traditional philosophical arguments about

> empiricism, instrumentalism, and relativity, at least in the sense that such arguments are based on truth as correspondence. Instead, constructivism offers science a more parsimonious paradigm of knowing as an adaptive function within a biological context with the purpose of coping with our experiential world, and language-based social interactions for achieving knowledge in communities. (Staver, 1998, p. 517)

Staver's position is antirealist as Matthews (1998) defines the term. To Staver, scientific knowledge is an entirely human construct. As there are multiple versions of constructivism (Geelan, 1997; Grandy, 1998), Staver's notion of "self-reference" and his highlight of individual efforts in the construction of scientific knowledge situate his position closer to the *humans the creator* side on Phillips' (1995) *humans the creator versus nature the instructor* continuum of constructivism. With its relativist views, Staver's position is quite different from other constructivist positions such as that set forth by Driver et al. (1994).

Driver et al. consider scientific knowledge the result of a community-based activity where "discursive" practices shape the construction, validation and communication of this knowledge. Their claims are more inclined towards the *nature the instructor* side of Phillips' (1995) continuum. Like Staver, Driver et al. engage in critical thinking about NOS. Driver et al. promise to "argue" that scientific knowledge is the result of a social and cultural activity. They write:

> We argue that it is important in science education to appreciate that scientific knowledge is both symbolic in nature and also socially negotiated. The objects of science are not the phenomena of nature but

> constructs that are advanced by the scientific community to interpret nature. (Driver et al., 1994, p. 5)

Based on their critical thinking, these scholars derive their respective NOS-related ideas. They claim that ontological entities (such as genes and chromosomes) and organizing concepts (such as evolution) are socially constructed. They write:

> These ontological entities, organizing concepts, and associated epistemology and practices of science are unlikely to be discovered by individuals through their own observations of the natural world. Scientific knowledge as public knowledge is constructed and communicated through the culture and social institutions of science. (Driver et al., 1994, p. 6)

Despite the argument that ontological entities are the results of social construction, Driver et al.'s constructivism is different from Staver's. Driver et al. note that "a view of scientific knowledge as socially constructed does not logically imply relativism" (p. 6). They base their position on the one proposed by Harré (1986) that scientific knowledge is constrained by how the world is, and that despite being socially constructed and validated, scientific knowledge has an empirical basis. Such a position favors the universality of science as Matthews (1994) would describe it, and discourages relativism because knowledge claims are thought to be evaluated by reference to an external world.

Staver's views of NOS are criticized by Norris and Korpan (2000), who believe that such views about science may compete with and even contradict science itself. Like the previously mentioned scholars, these scholars engage in critical thinking about NOS to "argue that some views on the nature of science that are found in the science education literature compete with substantive science" (p. 227). Norris and Korpan orient their claims particularly around the ontology and objectivity of science – notions highlighting their realist stance, as Matthews (1998) would describe it. They write:

> Characterized as ideas from the nature of science, they [some views of NOS] are advanced as being 'about' science, as if to suggest that they are outside the boundary of science. Yet, they cross the boundary in interesting and subtle ways, and trespass into the territory of science, thus inviting direct comparison with the substance of science itself. (Norris & Korpan, 2000, p. 227)

The scholars elaborate their argument by categorizing the substantive content of science as "first-order statements," and that of NOS as "second-order statements," showing instances where they might be in conflict. Accordingly, based on their critical thinking, Norris and Korpan argue that positioning claims as second-order statements implies that those claims are outside science itself; they assert, however, that "science has the resources to defeat metalevel claims." Norris and Korpan challenge scholars who treat science and NOS as independent discourses.

While Norris and Korpan (2000) may agree with Driver et al.'s view of scientific knowledge as being socially constructed, they are more critical about views of ontological entities than are Driver et al. These scholars differentiate between "ontologically subjective" entities, such as "hotel" and "ski resort," which would not exist independently of humans, and "ontologically objective" entities such as "rabbit" and "water," whose existence is independent of humans. For Norris and Korpan, scientific knowledge must have a universal characterization and must transcend culture because of the "ontologically objective" entities that it deals with. Such a position places Norris and Korpan further toward the *nature the instructor* side of Phillips' (1995) continuum.

The above discussion shows that Staver, Driver et al., and Norris and Korpan have engaged in critical thinking about NOS and have used it as the main mechanism for their debates. Based on their critical thinking they have derived their respective NOS-related ideas and claims. The ideas that they have produced are competing. In the paragraphs below I discuss the diverse recommendations that they put forth regarding NOS in school science.

Norris and Korpan (2000) suggest a pluralist view in dealing with conflicting views in the science curriculum, where students are taught the competing views and are then expected to arbitrate between them. They write:

> Rather than exclude the trespassing claims from science classrooms, our proposal is to explore a coordinated educational response that not only includes the ideas but turns their inclusion into an opportunity for science instruction. The response is based upon simultaneously teaching the substantive content of science and respecting a plurality of ideas. (Norris & Korpan, 2000, p. 240)

My reading of Norris and Korpan is that they want to move beyond establishing a common ground among different and competing views about science. The proposal entails respecting the various views about science in the science classroom and leaving it to students to form their own beliefs. Although such a recommendation may look neutral at first glance, a closer reading reveals that theses similar to Staver's will fail as soon Norris and Korpan's notion of *ontologically objective entities* is brought up because it cannot be true that such entities are entirely human constructions as Staver would argue.

Norris and Korpan provide two approaches for guiding students to respect various views about science and helping them to make their own minds. The first approach relies on "addressing reasons" (p. 242); in it, students are encouraged to seek and provide reasons for beliefs and actions to accept or reject not only scientific claims but also claims about NOS. The second approach relies on "providing coherence" (p. 242); the teacher guides the students to construct a coherent body of belief in spite of the presence of conflicting views between science and NOS.

Matthews (1998) takes a slightly different approach. He argues that science teachers today need to understand and be able to evaluate "the postmodern challenges of orthodoxy" (p. 163). His view is based on the fact that today more than ever, there exist different conceptualizations of what science is. He sets forth "a modest proposal" (p. 168) whereby students are given some opportunity to understand the meanings and conditions of correct use of meta-level terms such as law, theory, hypothesis, evidence, and model, and higher-level debates are reserved for more advanced settings. Matthews' proposal may create controversial issues because the meanings of these terms inform higher-level debates. For example, the nature of theories and laws might be quite different for a postmodernist and a realist.

Staver (1998), on the other hand, draws a parallel between how learning occurs in the classroom and how scientists generate scientific knowledge. Staver (1998) claims that "the purpose of cognition in a constructivist perspective and the origins of students' alternative conceptions are synchronous" (p. 517). Later he cites Wandersee's, Mintzes', and Novak's (1994) synthesis of research on alternative conceptions to claim that current science pedagogy is based not only on constructivism and conceptual change, but also on Kuhnian science. Hence, according to Staver, there is a relationship between learning in the science classroom and NOS.

If NOS is best understood from a constructivist framework and if there is a relationship between how learning occurs in the science classroom and how scientists develop scientific knowledge, it is not surprising that Staver would want NOS to be taught and learned within a constructivist framework. Consequently, there could be no room for exposing students to multiple positions of NOS. There are at least two problems that arise here.

The first problem pertains to the very essence of the goals of education. Good education needs to provide opportunities so that students are exposed to multiple perspectives (on NOS) in order that they can develop their own viewpoints. Unfortunately, Staver's recommendation hinders students from developing their own views. Matthews' (1998) concern is valid here – epistemological development may change its character and turn into "believing what I believe about epistemology" (p. 167). To him, this might end up being indoctrination rather than education.

The second problem is related to the distinction between constructivism as an epistemological doctrine and constructivism as a learning theory. Staver falls short in explicating such a distinction when drawing a similarity between pedagogy and NOS. Other constructivists are more careful. Driver et al. (1994) are more cautious in establishing such a similarity between science learning and NOS, perhaps because they are more conscious of the dichotomy between constructivism as epistemology and as learning theory. They write:

> [W]e argue that viewing learning as theory change puts too great an emphasis on the theory-like nature of students' informal ideas. We argue that their tacit and situated nature distinguishes them from scientific theories. Furthermore, learning science in school means more than changing from one set of theories to another; it means being consciously articulate about what constitutes theories in the first place. (Driver et al., 1994, p. 9)

Before moving to the next section, it will be useful to summarize this one and highlight its contributions. I presented a set of two debates from the science education literature to show the contested nature of these debates. I highlighted the role of critical thinking in those debates. Critical thinking constitutes the main tool for these scholars to engage in philosophical debates, the NOS-related ideas that come out of these debates are products of critical thinking, and the recommendations set forth about how to approach NOS in school science are quite divergent. No matter how diverse, and often competing, they present value and significance from a scholarly point of view. Yet there is another point. The practice of education cannot move forward without the translation of such diverse recommendations into action. This is a challenge for empirical researchers and science policy and curriculum developers. Despite belonging to different philosophical camps, they need to find ways of addressing NOS in the science classroom in the midst of diverse and competing viewpoints and recommendations. In the next section I compare the features related to philosophical discourse on NOS that I have identified in this section to features related to consensus frameworks of NOS in school science. I indicate a number of features that makes the latter non-authentic, in terms of how it portrays the substantive content of NOS and the process of its development.

Consensus frameworks of NOS in school science. Taking into consideration the diverse and competing viewpoints on NOS prevalent in philosophical circles, there is some agreement among many science educators that NOS in school science is not intended to introduce students to these diverse and competing views. Instead there is a need for some sort of convergence. Consensus frameworks converge or bring together the diverse philosophical viewpoints of NOS with the purpose of delineating what needs to be addressed under the title of NOS in school science. Proponents of such frameworks (e.g., Abd-El-Khalick et al., 1998; Lederman, 2004) tend to create convergence by highlighting a set of NOS-related ideas (see the list in Chapter 1) that form a common denominator among the different philosophical viewpoints and set forth the claim that *K-12* *science education should target only the teaching of general aspects of NOS* (e.g., Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick et al., 1998; Lederman, 2004). This claim is often justified on pragmatic grounds. Proponents suggest that (1) there is little controversy among philosophers of science on these general aspects, and that (2) the goal of NOS instruction in K-12 science education is not to provide a philosophical training to students, but rather to equip them with tools so that they can become scientifically literate individuals. Though promising at a first glance, these pragmatic justifications seem to create significant undesirable consequences that outweigh the decision that K-12 science education should target only the teaching of general aspects of NOS. I discuss the reasons later in this section.

Lederman (2004) claims that his research group has set forth seven general aspects of NOS that they judged important to be included in science curriculum and instruction (Abd-El-Khalick & Lederman, 2000a; Lederman, 2004). Lederman claims that three criteria have guided his research group to come up with these general aspects of NOS. These criteria are the extent to which the aspect is accessible to students, whether there is general consensus on a particular aspect, and whether the aspect is useful for citizens' everyday lives. These seven aspects of NOS have received positive reviews among many science educators (e.g., Akerson et al., 2011; Bell, Lederman, & Abd-El-Khalick, 2000; Gess-Newsome, 2002; Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Kim & Irving, 2010; Schwartz et al., 2004; Yacoubian & BouJaoude, 2010).

Osborne et al.’s (2003) study also endorses the general aspects of NOS, yet approaches the issue from a totally different angle. These researchers provided empirical evidence of what the expert community of scientists, philosophers, historians, science educators, science communicators, and sociologists of science think are important aspects of NOS that should be addressed in K-12 science education. The authors argued that determining these aspects of NOS “requires some level of agreement (if not complete agreement) about some form of canonical version of the processes and practices of science and which elements are essential components of any school curriculum” (p. 695). The researchers used the Delphi method with three rounds of sequenced, open-ended questionnaires to establish the degree of consensus of 23 experts. Osborne et al. found broad agreement within the expert community on nine themes, as well as agreement that the aspects of NOS represented by the nine themes are interrelated and, consequently, cannot be addressed in isolation.

While the method utilized by Osborne et al. based on empirically deriving the themes of consensus may be considered a strength of their study, there are at least two issues worth highlighting. The first is related to the number of participants who constituted the “expert” group. Acknowledging that there are diverse viewpoints on NOS among different discourse communities, the representativeness of the sample becomes an issue. While Osborne et al.’s sample was drawn from different discourse communities, the different viewpoints within these communities were not necessarily taken into consideration. For instance, the total number of historians, philosophers, and sociologists of science in the expert group was five. Even if one assumes that these five participants represented five different views of NOS, one may not assume that those five different views of NOS are representative of the total views of NOS among historians, philosophers, and sociologists. This leads to a second, related issue that the 23 experts in Osborne et al.'s study cannot be representative of the expert community from which they were chosen.

Alters (1997a) obtained the views of philosophers of science on what they thought of the NOS tenets proposed by science education researchers and organizations. The researcher sent these tenets to members of the Philosophy of Science Association (PSA). Alters' analysis of the 176 surveys showed that the participants expressed major criticisms of some of the basic tenets that science education researchers and organizations endorsed. Moreover, different philosophers of science varied in their views about the tenets of NOS. This work became an issue of debate between Smith, Lederman, Bell, McComas, and Clough (1997) and Alters (1997b). The former group claimed:

> [I]t appears that this study was designed and the data interpreted in such a way as to create the false impression that there is great disagreement about the NOS tenets relevant to K–12 instruction. Although the extent of the agreement remains unclear, we maintain that the data collected by Alters can, in fact, be interpreted to the opposite conclusion that there is a considerable consensus about the foundational tenets of the NOS. We encourage K–12 teachers to ignore Alters' biased study and instead focus

> on instruction that is consistent with the recently published standards documents. (Smith et al., 1997, p. 1103)

Alters (1997b) claimed that his critics were defending an ideology. After justifying his positions and interpretations, Alters responded:

> These views strike me as condescending to teachers and deeply unhealthy. My recommendation would be the opposite: to expand one's vision by examining all sides of an issue and always to ask, "whose NOS?" (Alters 1997b, p. 1107)

Driven by Alters' (1997a) findings, I move now back into my earlier claim that the pragmatic justifications made by proponents of the consensus frameworks of NOS create significant undesirable consequences. My analysis reveals four challenges associated with the consensus framework of NOS in school science that I discuss in the subsequent paragraphs. I use these four challenges to support my overall argument that the consensus frameworks do not present an authentic image of the substantive content of NOS and the process of its development.

First, the claim that *K-12 science education should target only the teaching of general aspects of NOS* is justified by the proponents of consensus frameworks in that there is consensus among philosophers of science on those general aspects of NOS. Upon closer examination of this justification there appears to be consensus among philosophers, but it is indeed only an *apparent* consensus at the surface level. Accordingly, although the aspects derived from the 23 experts in Osborne et al.'s (2003) study and those set forth by Lederman (2004) may appear to show some consensus, the details related to these aspects do not necessarily reveal a consensus. As examples, consider the following themes from Osborne et al.'s (2003) and Lederman's (2004) studies. The theme derived by the expert community in Osborne et al.'s study, namely "Diversity of scientific thinking" (p. 707), focuses on the basic idea that there are different ways of doing science and different methods for solving problems. The theme set forth by Lederman (2004), namely "scientific knowledge is socially and culturally embedded" (p. 1063), highlights the idea that scientific knowledge does not develop in vacuum, but rather that its development is guided by scientists who operate in various sociocultural contexts. These NOS-related themes might seem to be non-controversial among philosophers no matter which camps they belong to. Nonetheless, I concur with Matthews' (1994) claim that these themes may be only *apparently* non-controversial. Once the surface is scratched the controversies appear – philosophers' interpretations of *diversity of scientific thinking* and *social and cultural embeddedness* are not the same. The debates on the role of culture in science and the status of Western Science (Cobern & Loving, 2001; Siegel, 1997; Snively & Corsiglia, 2001; Stanley & Brickhouse, 2001) discussed in the previous section illustrates this point. A robust multiculturalist, to use Matthews' (1994) words, might consider diversity of scientific thinking to encompass traditional or Indigenous ways of understanding the world as valid as the methods utilized by Western Science. By contrast, a universalist might argue for the universal characteristics of scientific thinking regardless of an existing diversity. As far as the social and cultural embeddedness of science is concerned, philosophical views on the role of culture and the extent to which it does (or does not) shape scientific knowledge development are also quite variegated. Consequently, the themes derived by Lederman and Osborne et al. are based on an *apparent* consensus limited to the surface level. A legitimate concern to raise is the morality of using an apparent consensus as a foundation for NOS in school science.

Second, science educators may, often unconsciously and unintentionally, create another undesirable consequence as a result of the convergence mechanism. By treating the apparent consensus as foundational in school NOS, they provide a non-authentic image of the philosophical debates on NOS, presenting an image of the nature of NOS at the metalevel as being absolute and definite. Many science educators (e.g., Akindehin, 1988; Khishfe & Abd-El-Khalick, 2002; Lederman, 2004) have argued that developing informed understandings of NOS is a cognitive instructional outcome. Accordingly, both Osborne et al.'s theme (on the diversity of scientific thinking) and Lederman's theme (regarding science as being socially and culturally embedded), when changed into cognitive instructional outcomes (regardless of how general or specific), would result in absolute statements giving the implicit message that there are no debates among philosophers on these respective aspects of NOS. The statements would not portray an image of the competing viewpoints on *diversity* and the *role of culture* that we find inside philosophical circles. Consequently, although convergence is primarily for pedagogical purposes, the end result is a set of non-contested statements in the form of objectives that do not offer an authentic image of the competing and diverse content on NOS found in the philosophical literature.

Third, as the ultimate goal is for students to develop understandings of general aspects of NOS, it is not surprising that the primary emphasis is placed on the substantive content of NOS itself rather than the *process* through which that substantive content has been constructed. Critical thinking that is so central among philosophers as a means for debating and coming up with the NOS-related ideas is placed only in the background of school NOS as far as consensus frameworks are concerned, while the NOS-related ideas – detached from the process of their development – have received priority and have been situated in the foreground of NOS instruction.

Considering the same examples, if learners were guided to develop an understanding of the diversity of scientific thinking (after Osborne et al.) or an understanding that science is socially and culturally embedded (after Lederman), then the primary focus would be placed on the NOS-related ideas themselves rather than the process of how these ideas are produced. The nature of the relationship between the substantive content and the process of its development is quite different in philosophical circles. As I showed earlier, the philosophical debates on NOS rely on critical thinking not only as a main mechanism of debate about NOS but also as a main tool for generating the substantive content of NOS.

Had the *process* been a highlight in consensus frameworks, critical thinking would have been in the foreground of NOS instruction, with the objective of guiding students, for instance, to *argue* whether science is socially and culturally embedded, and to *demonstrate* whether scientific thinking is diverse. Deploying verbs such as "argue" or "demonstrate" would bring critical thinking to the foreground of NOS instruction and would move substantive content into the background.

Fourth, let us consider the second justification for consensus frameworks – that the goal of teaching NOS in school science is not training students to become philosophers, but rather equipping students with the tools needed to become scientifically literate individuals. I acknowledge that school students do not need to be exposed to sophisticated viewpoints about NOS; they might not be there yet. Taking such a position, however, does not justify the exemption of students from engaging in and developing critical thinking *about* NOS and *with* NOS. This is especially important as many science educators hope that learners will eventually be able to use or apply their NOS understandings to make informed decisions on socioscientific issues (e.g., Bell & Lederman, 2003; Khishfe, 2012; Kolstø, 2001a; Zeidler et al., 2002). Learners need to be trained to think critically *with* their NOS understandings, but they also need to be trained to think critically *about* NOS so that they can eventually make decisions on socioscientific issues.

Suppose a future citizen is to make a judgment about whether Indigenous Knowledge should be taught in her child's science class. Specifically, she needs to make a judgment and determine whether Indigenous Knowledge is science or not. Suppose as well that the future citizen has adequate understanding of the aspect related to the social and cultural embeddedness of science according to the definitions given by the proponents of consensus frameworks. There are at least two issues that would arise here. First, the future citizen would not be able to use or apply her general understanding of social and cultural embeddedness of science to make decisions on whether Indigenous Knowledge is science because the surface level understanding that she holds cannot sufficiently constitute raw materials for her to engage in critical thinking with them. Second, even if we assume that her understanding of the social and cultural embeddedness of science is sufficient so that she could think critically with them, she still does not have the necessary training that would enable her to engage in critical thinking with her understanding of social and cultural embeddedness. In order to make a decision on whether Indigenous Knowledge is science, the future citizen needs to be trained to think critically *with* her understanding of social and cultural embeddedness but also needs to be trained to think critically *about* social and cultural embeddedness.

My point is quite straightforward: The claim that *training students to become philosophers is not a goal in science education* does not justify the exemption of students from engaging in and developing critical thinking *about* NOS and *with* NOS. Siegel (1980) considers critical thinking an educational ideal. As teaching involves interaction among persons, Siegel argues that such interactions ought to correspond to the moral requirements of interpersonal interactions in general, among which showing "respect for persons" (p. 13) is of high significance. From Siegel's point of view, then, limiting instruction to general aspects of NOS would create the problem of science educators granting more weight to their own interests than to the interests of their students, resulting in the loss of equal worth, which forms the basis of the respect all persons are due.

Summary. My critical evaluations of philosophical discourse on NOS in science education and the consensus frameworks of NOS in school science reveal that within the same community of science education, the philosophical debates and the consensus frameworks are not congruent. Critical thinking constitutes an explicit objective in the writings of scholars who are engaged in philosophical debates on NOS and is almost always in the foreground of these debates. Moreover, the NOS-related ideas that these scholars set forth are presented as a byproduct of their critical thinking. Furthermore, the NOS-related positions held by those involved in the debates are quite divergent and competing. On the other hand, consensus frameworks of NOS in school science demonstrate a different image. NOS-related ideas are in the foreground of these frameworks, and understanding these ideas constitutes an explicit objective. The NOS-related ideas are detached from the process of their development and present convergence, and are non-competing. Consequently, consensus frameworks of NOS in school science present a non-authentic and a distorted image not only of the substantive content of NOS but also of the process of how the substantive content of NOS develops. Table 1 summarizes the main features of the philosophical discourse on NOS compared to those of the consensus frameworks of NOS in school science.

Table 1

Features of the Philosophical Discourse on NOS and Consensus Frameworks of NOS in School Science

Philosophical Discourse on NOS	Consensus Frameworks of NOS
Critical thinking constitutes an explicit objective	NOS-related ideas constitute an explicit objective
Critical thinking about NOS is in the foreground of the philosophical debates	NOS-related ideas are in the foreground of the consensus frameworks of NOS in school science while critical thinking about NOS is in the background
Substantive content of NOS is always a byproduct of critical thinking	NOS-related ideas are detached from the process of their development
NOS-related positions derived by scholars engaged in the debates are quite divergent and competing	NOS-related ideas present convergence and are non-contested

Lack of a Developmental Trajectory for Learning NOS

In this section I show that the consensus frameworks of NOS in school science do not situate NOS learning across a developmental trajectory. A review of the literature shows that science educators address the same NOS-related ideas in the same fashion at different grade levels. I use the *tentative aspect of NOS* to illustrate this point.

A justification often given for why science educators need to limit their instruction to general NOS-related ideas is that these ideas are thought to be developmentally appropriate to school students – that is, that K-12 students can handle the level of abstraction presented by the general NOS-related ideas but cannot handle a level beyond that (Lederman, 2004). A closer examination of the literature shows that there is no pedagogical sequence for NOS in K-12 science education. Learning certain general ideas of NOS, such as the notion that science is a tentative endeavor, is thought to be developmentally appropriate for Grade 6 students (e.g., Khishfe & Abd-El-Khalick, 2002; NRC, 1996). If we assume that this claim is true, then we should expect that Grade 12 students would be exposed to cognitively higher objectives related to the tentative NOS because the latter are at a cognitively more advanced stage. This expectation is not fulfilled (see NRC, 1996). In fact, understanding the same aspect in its same form (science is a tentative endeavor) becomes an objective in Grade 12. Furthermore, the same aspect in the same form becomes also an objective in pre-service science teacher education. Consequently, the justification that *general aspects of NOS are developmentally appropriate* fails because students in Grades 6 and 12 and pre-service science teachers are not at the same developmental stage. I illustrate my claims with particular examples in the paragraphs that follow.

Many science educators as well as science education policy and curriculum documents (e.g., CMEC, 1997; Lederman, 2004; NRC, 1996) claim that students need to develop understandings of the tentative aspect of NOS. The

NSES (NRC, 1996) document sets forth the following standard regarding the tentative aspect of NOS essential for the Grade 5 to 8 level:

> Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations. (NRC, 1996, p. 171)

The tentative aspect of NOS gets addressed in a very similar way, once again as an important standard at the Grade 9 to 12 level, in the same document:

> Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. (NRC, 1996, p. 201)

Assuming that students at the Grade 5 to 8 level had developed adequate understandings corresponding to the aforementioned standard, the document does not provide any information of how students would need to go deeper in exploring the tentative aspect of NOS at the Grade 9 to 12 level. The tentative aspect of NOS is not placed in a developmentally appropriate sequence where learners could potentially build more thorough understandings of it over time. The same problem is also evident in intervention studies that have tried to improve learners' understandings of the tentative aspect of NOS, along with other ideas.

Akerson and Donnelly (2010) used explicit and reflective instruction in the context of guided and authentic inquiry activities to develop K-2 students' understandings of NOS. The researchers reported that the students improved their NOS understandings over the 6-week-period of the program. Students developed more adequate understandings of certain NOS-related ideas including the tentative aspect of NOS. An informed understanding of the tentative aspect of NOS, according to the coding rubric used by these researchers, included such student answers as "Science changes as we learn more or as scientists reinterpret existing data" (p. 108). Adequate understandings included statements such as "As we learn more or we have new technology science changes" (p. 108). The tentative aspect of NOS taught to early elementary-level students by Akerson and Donnelly is addressed in quite a similar manner at the middle school level.

Khishfe and Abd-El-Khalick (2002) guided Grade 6 students to discuss and reflect on the tentative, empirical, inferential, imaginative and creative aspects of NOS. The students engaged in inquiry activities, after which the experimental group students engaged in explicit and reflective discussions related to the target aspects of NOS. The researchers used the Benchmarks for Science Literacy (AAAS, 1993) and NSES (NRC, 1996) documents to identify what NOS understandings their Grade 6 students needed to develop related to each target NOS aspect. The following quote from the Benchmarks (AAAS, 1993) illustrates what Grade 6 students need to understand about the tentative aspect of NOS:

> Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way. (AAAS, 1993, p. 7)

The researchers found that an explicit and reflective inquiry-based approach was more effective than an implicit inquiry-based approach in developing learners' understandings of NOS. Indeed, many students in the experimental group developed more adequate understandings of the tentative and other aspects of NOS. Similar findings were reported by Yacoubian and BouJaoude (2010) in the context of the science laboratory with Grade 6 students. We investigated the impact of explicit and reflective discussions following inquiry-based laboratory activities on sixth graders' views of the tentative, empirical, social and subjective aspects of NOS. As far as the tentative aspect is concerned, we used a framework similar to the one developed by Abd-El-Khalick et al. (1998) to classify students' views as adequate, partially adequate or inadequate. Accordingly, students categorized as having adequate understandings related to the tentative aspect of NOS viewed scientific knowledge as subject to change where certain scientific claims could be abandoned and replaced by others. Like Akerson and Donnelly's (2010) study, both Khishfe and Abd-El-Khalick's (2002) and Yacoubian and BouJaoude's (2010) studies focused on explicit and reflective discussions as a means for guiding students to develop an understanding that science is subject to change based on new interpretations, information and technology.

At the secondary level, similar expectations are made for students in terms of developing adequate understandings of the tentative aspect of NOS. Bell et al. (2003) studied the effect of an inquiry-oriented science apprenticeship program on a group of secondary students' (Grades 10 and 11) understandings of NOS. The researchers used the AAAS (1989) and NSES (NRC, 1996) documents to delineate what they expected students to show as evidence of adequate understandings of NOS, including the tentative aspect of NOS. The students engaged in authentic science experiences with mentor scientists, yet they did not develop adequate understandings of NOS after they completed the apprenticeship program. Indeed, as far as the tentative aspect of NOS is concerned, the students believed theories can change, yet they related tentativeness to a lack of information. The authors attributed the students' inability to form adequate understandings of NOS to the fact that they had not received explicit and reflective instruction on NOS over the course of the apprenticeship.

The expectations do not become any higher for in-service and pre-service science teachers. In the context of in-service science teacher education, Akerson & Hanuscin (2007) studied the influence of a three-year-long professional development program on elementary teachers' views of NOS, their instructional practices to promote NOS understandings among their elementary students, and their students' views of NOS. The researchers focused on six aspects of NOS that are believed to be accessible to K-6 students. These included the tentative, empirical and subjective aspects of NOS; the role of creativity and imagination; the social and cultural embeddedness of science; and the functions of observations and inferences. The teachers received explicit and reflective training in NOS, embedded in an inquiry-based program. The researchers reported positive changes among the teachers and most of their students regarding their NOS understandings. For the tentative aspect of NOS, many teachers and their elementary students developed understandings consistent with current reform proposals.

In the context of pre-service science teacher education, Schwartz et al. (2004) investigated the development of NOS understandings of pre-service science teachers during a science research internship course. At the completion of the internship, participants demonstrated either a "major" change in their understandings or an "enhancement" compared to their initial understandings of NOS. Adequate understanding of the tentative aspect of NOS was described as follows by the researchers:

> Scientific knowledge is subject to change with new observations and with the reinterpretation of existing observations. All other aspects of NOS provide rationale for the tentativeness of scientific knowledge. (Schwartz et al., 2004, p. 613)

The researchers identified three factors essential for the development of the participants' understandings of NOS: active reflection, the scientific inquiry context, and perspective-taking, which the researchers called as the "reflection from the outside" (p. 635).

The studies reviewed in this section suggest that explicit and reflective NOS instruction helped learners to develop more informed understandings of

NOS. Informed understandings of NOS were usually judged to be ones that were consistent with reform proposals such as AAAS (1993) and NSES (NRC, 1996). In many of these studies, after engaging in certain learning experiences, students or teachers were involved in explicit and reflective discussions on certain NOS-related ideas with the purpose of forming more adequate understandings. I focused in this section on the tentative aspect of NOS as an example.

The participants at all developmental levels were exposed to the tentative aspect of NOS in the same way with no increase in curricular sophistication. Moreover, the expectations were almost the same for students at different levels, as well as for pre- and in-service science teachers, regarding what would count as a desired understanding of the tentative aspect of NOS. Although my focus above was on the tentative aspect of NOS, the same argument holds true for other aspects of NOS as well. This conclusion raises a series of questions: Pedagogically speaking, how justifiable is it to keep most NOS-related ideas at the same cognitive level across the science curriculum? In other words, how justifiable is it to address the same NOS-related ideas for learners at different developmental stages? Moreover, from a moral perspective, how justifiable is it to address the same list of NOS-related ideas repeatedly, year after year, from K to 12 and in teacher education programs? As Abd-El-Khalick (2012b) argues, it may be time to think about ways to address NOS at increasing levels of depth. In Chapters 3 and 5, I consider developmental possibilities for NOS in school science and focus on learning progressions as a possible framework that could support the construction of a developmental trajectory. However, before moving forward, I shed light on the recent draft of the *Next Generation Science Standards* (NGSS, 2012a) in the US. There is some improvement with respect to the NSES standards (NRC, 1996) in terms of developmental issues regarding NOS learning, despite other shortcomings that I highlight below.

In the *Next Generation Science Standards* (NGSS, 2012a), practices and crosscutting concepts are considered the bases upon which students can learn NOS. As these elements are integrated with the substantive science content in the standards, we notice that they do not get addressed in the same way from the K-12 levels. For instance, consider the following:

> At the K-2 level students who demonstrate understanding can…
>
> Provide evidence that humans' uses of natural resources can affect the world around them, and share solutions that reduce human impact. (NGSS, 2012a, K.0TE.d.)
>
> At the 9-12 level students who demonstrate understanding can…
>
> Use evidence to support explanations for the relationship between a region of the brain and the primary function of that region. (NGSS, 2012a, HS.LS-SFIP.e)

Notice that in both cases, students engage in the practice of engaging in argument from evidence, yet the context changes to match to the developmental and/or cognitive abilities of the students. Nonetheless, the document does not clarify what students would need to learn *about* evidence.

In the position paper *Nature of Science in the Next Generation Science Standards* (NGSS, 2012b), the following example is used to illustrate how the elements of *practices* and *crosscutting concepts* could be put together in order to help students develop NOS understandings:

> Suppose students observe the moon's movements in the sky, changes in seasons, phase changes in water, or life cycles of organisms. One can have them observe patterns and have them propose explanations of cause-effect. Then have the students develop a model of the system based on their proposed explanation. Next, they design an investigation to test the model. In designing the investigation they have to gather data and analyze data. Next they participate in the practice of constructing an explanation using an evidence-based argument. A science teacher may also probe students' understanding of possible mechanisms for the phenomena they observe. (NGSS, 2012b, p. 2)

Although the above example elucidates what practices the teacher would need to engage her students in (making observations, proposing explanations, developing and testing models, designing investigations, and collecting and analyzing data), the example does not emphasize the significance of engaging students in explicit discussion of the underlying concepts of these practices. It is assumed that when students engage in these practices they will develop understandings of NOS. However, as discussed earlier, students do not develop their NOS understandings without explicit instruction. Explicit reflective discussions are more effective in developing NOS understandings than is implicitly engaging students in the above mentioned activities. This is a major shortcoming in the draft of the new generation science standards in the US. In a recently published response from the National Science Teachers' Association (NSTA, 2012) in the US, the association presented a similar criticism of the NGSS document, claiming that the latter fails to address NOS. It recommended including a section on connections to NOS and history of science as the final version of the document is prepared.

Refocusing the Discussion

In this chapter I presented a critique of the consensus frameworks of NOS in school science. I argued that that these frameworks (1) lack clarity in terms of how the NOS-related ideas could be applied for various ends, (2) portray a distorted image of the substantive content of NOS and the process of its development, and (3) lack a developmental trajectory for how to address NOS at different levels. In the next chapter I explore the possibility of a NOS curriculum that builds upon these three arguments.

Chapter 3

The Need for a NOS Curriculum

My main objective in this chapter is to provide a rationale for why a NOS curriculum is needed. I divide the chapter into five parts. In the first part I adopt a notion of curriculum for the purpose of this study. In the second part I argue that a precise purpose is needed to teach NOS in school science. School science needs to guide students not only to develop NOS understandings but also to make connections between those understandings and decisions regarding socioscientific issues. In the third part I propose *critical thinking* as a foundational pillar for NOS in school science. In the fourth part I highlight the need to place NOS in school science on a developmental pathway. Finally, in the last part I argue that when the proposals set forth in this chapter are adopted, it will be legitimate to talk about a *NOS curriculum in school science* rather than *NOS-related ideas in school science.*

A Notion of Curriculum

Schiro (2008) identifies four competing curricular ideologies underlying a *war* that educators have been engaged in for more than a century regarding the nature of the American school curriculum. These ideologies are the following: (1) a scholarly academic ideology that highlights the importance of academic disciplines as the basis upon which decisions of what to teach have to be made, (2) a social efficiency ideology that highlights the importance of efficiently meeting the needs of the society, (3) a learner-centered ideology that focuses on the needs and concerns of individuals, and (4) a social reconstruction ideology that focuses on the significance of facilitating the construction of a more just society. These curricular ideologies, according to Schiro, influence ways of thinking about curriculum just as political beliefs may influence ways of thinking about political issues. Schiro's choice of the term *ideology* instead of *philosophy* is a deliberate decision. He claims that educators dealing with curriculum are not necessarily conscious of the major assumptions underlying their actions. To him, expressed intent (philosophy) might not necessarily translate into actual behavior. Nonetheless, he acknowledges that the four curricular ideologies are fundamentally philosophical in nature.

Curriculum theorists are often devoted to examining the philosophical foundations of curricula by engaging in curriculum inquiry. The latter is a vibrant area of research in education; its different traditions seek to answer questions related to what to teach, why to teach, and how to teach. Traditions of curriculum inquiry are fundamentally philosophical in nature. Curriculum theorists draw from philosophical positions to justify their research aims, *approaches* and criteria for validating new knowledge. Moreover, they often name their respective tradition after the philosophical position in question. Some of these philosophical positions are captured quite well by Phillips and Burbules (2000) and Prasad (2005).

Phillips and Burbules differentiate between foundationalism and postpositivism as two major epistemologies. Foundationalist epistemologies, they write, are divided into empiricism and rationalism, with positivism being a form of empiricism. Foundationalists consider an item as *knowledge* if the item has a secure foundation in observable phenomena. Postpositivism, on the other hand, is considered to be a non-foundationalist approach to human knowledge that arose as a result of critiques to foundational epistemologies. Non-foundationalists reject the view that knowledge is based on secure foundations. Prasad (2005) further divides postpositivist perspectives into four main traditions. These are (1) “the interpretive traditions” (p. 13), such as hermeneutics, that take human interpretations as a starting point for knowledge generation, are rooted in the thinking of Immanuel Kant, and are referred to as the German idealist tradition; (2) the “traditions of deep structure” (p. 91), such as structuralism, that are rooted in the conviction that knowledge of social phenomena could be advanced by studying their deep structural underpinnings; (3) “the critical traditions” (p. 109), such as critical theory, feminism and historical materialism, that examine social interactions through the lenses of power, conflict and domination; and (4) “traditions of the post” (p. 211), such as poststructuralism, postmodernism and postcolonialism, broadly referred to as positions intended to critique modern Western thinking from both within it and outside of it.

The central purpose of the present research is to explore an alternative way of addressing NOS in school science. I study the potential of replacing NOS-related ideas in school science by a NOS *curriculum*. In doing so I am defending a “scholarly academic ideology”, to use Schiro’s words, highlighting the importance of using the academic discourse on NOS as the basis upon which to make decisions about what and how to teach. As argued previously, a NOS curriculum would create a space for the substantive content of NOS and the process of its development (critical thinking) to coexist in a more authentic way. Consequently, a driving factor for my vision is to address NOS in school science as authentically as possible. This position does not underestimate, however, the significance of the needs of the society and/or the learner. In fact, I highlight the significance of the societal needs through arguing that the NOS curriculum ought to target NOS as a means for socioscientific decision making and as an educational end in order to foster scientific literacy. Moreover, I highlight the significance of the individual learner's needs through arguing that the NOS curriculum ought to provide a developmental pathway for NOS learning.

My intention here is not to engage in curriculum inquiry. Entering into philosophical debates on the nature of curriculum would divert the objective of this study. The present study sets loose, pragmatic boundaries for an operational definition of curriculum. Walker's (2003) broad definition of curriculum is used as guidance. His definition, "a particular way of ordering content and purposes for teaching and learning in schools" (Walker, 2003, p. 4), brings together the content, purpose and organizational aspects that are central for any curriculum. The emphasis placed on *a* (rather than *the*) *particular way* might show the complex nature of curriculum development with (often competing) social, cultural and political influences. Indeed Walker (2003) starts the preface of his book by acknowledging that "What a society should teach their children is one of those nasty but wonderful problems that is impossible to solve and impossible to avoid" (p. xiii).

Van den Akker, Fasoglio, and Mulder (2010) differentiate between five levels of curriculum: the *supra* at the international level, *macro* at the societal or national level, *meso* at the school level, *micro* at the classroom level and *nano* at the individual level. The present study is mostly concerned with the supra and the macro levels; it also includes an empirical study at the meso level. The need for informed understandings of NOS as a cornerstone for scientific literacy is highlighted in many national curriculum documents (e.g., AAAS, 1993; CMEC, 1997). At the macro level there is some tendency among science educators to view the role of NOS in terms of democratic decision making and good citizenship (Driver et al., 1996; Kolstø, 2001a). Nonetheless, it seems that the need to prepare scientifically literate citizens goes beyond local needs in today's globalized era, as many of the problems of the century, from the impact of climate change and global warming to the need for sustainable energy use, are not only local but also global challenges that do not necessarily recognize geographical borders and political boundaries.

From another perspective, Van den Akker (1998) describes a list of curricular representations:

- The *ideal* curriculum: the original vision underlying a curriculum (basic philosophy, rationale, or mission);
- the *formal* curriculum: the vision elaborated in a curriculum document (with either a prescribed/obligatory or exemplary/voluntary status);
- the *perceived* curriculum: the curriculum as interpreted by its users (especially teachers);

- the *operational* curriculum: the actual instructional process in the classroom, as guided by previous representations (often referred to as the curriculum-in-action or the enacted curriculum);
- the *experiential* curriculum: the actual learning experiences of the students;
- the *attained* curriculum: the resulting learning outcomes of the students. (Van den Akker, 1998, pp. 421-422)

In this study my intention of providing *good* reasons for a NOS curriculum and arguing for what *ought to* be done makes the study normative in nature. My goal in the first part of this study has been to envision a NOS curriculum with particular characteristics and to explore its potential in school science. Consequently, the present study can be viewed as contributing to an *intended* curriculum (Van den Akker, 2003) as it focuses mainly on laying out a vision. Van den Akker's notion of the intended curriculum encompasses the *ideal* as well as the *formal* curriculum in his list of curricular representations above (Van den Akker, 1998). In the second part of this study, I propose the CT-NOS framework and explore experienced secondary science teacher's views of a lesson prepared using this framework. The second part of the study can be regarded as contributing to a *perceived* curriculum according to Van den Akker's (1998) list.

Bulte, Westbroek, de Jong, and Pilot (2006) argue that a curriculum design process takes place in several cycles. The cyclic process, according to the researchers, reduces the gap between the ideal curriculum and what is implemented. The first cycle starts when there is dissatisfaction with the current operational curriculum. In this study, the need for an alternative way of addressing NOS in school science was justified based upon my dissatisfaction with the consensus frameworks of NOS that I presented in Chapter 2. Bulte et al. (2006) claim that the second stage in a curriculum design process involves the selection of appropriate theoretical ideas so that the transformation of the ideal curriculum into a formal representation is possible. The present study looks for an alternative way to address NOS in school science. I borrow theoretical ideas such as *critical thinking* and *learning progressions* in setting forth a proposal for how to do so.

The subsequent stages of Bulte et al.'s (2006) cycle of curriculum design processes include building curriculum materials; identifying an operational curriculum; and developing instruments to evaluate the operational, experiential and attained curricula. The second part of the present study could be regarded as contributing towards building curriculum materials and identifying an operational curriculum. However, it is beyond the scope of the study to fully develop curriculum materials or identify an operational curriculum.

Bulte et al.'s first two stages of the curriculum design cycle are aligned with the *rationale*, *aims / objectives* and *content* of the curricular components of Van den Akker (2003) and Van den Akker et al. (2010). These researchers identify ten components of a curriculum. For them, a major challenge of curriculum improvement is to create balance and consistency among these components. The curricular components are the (1) rationale (why students are learning), (2) aims and objectives of what students are learning, (3) content (what they are learning), (4) learning activities (how they are learning), (5) teacher role, (6) materials and resources, (7) grouping (with whom they are learning), (8) location (where they are learning), (9) time (when they are learning), and (10) assessment.

Accordingly, the present study raises the questions of why students should learn NOS (*Rationale*), in pursuit of which goals they should learn NOS (*Aims and objectives*), and what they should learn under the title of NOS (*Content*). Moreover, the second part of the study contributes to developing *materials and resources* (Van den Akker, 2003; Van den Akker et al., 2010).

Taking into consideration the pragmatic definitions of curriculum set forth in the previous paragraphs, in the next section I argue that a precise purpose is needed to teach NOS in school science. I argue that school science needs to guide students not only to develop NOS understandings but also to make connections between their NOS understandings and decisions regarding socioscientific issues.

NOS as an Educational End and NOS as a Means for Socioscientific Decision Making

In the previous chapter I criticized the consensus frameworks of NOS in school science for addressing NOS only as an educational end. I argued that consensus frameworks of NOS do not explicate how future citizens can apply their NOS understandings to making decisions about socioscientific issues. In the following paragraphs I argue that a more precise purpose is needed to teach NOS in school science. I review the literature of NOS and socioscientific decision making in more depth and argue that both NOS as an educational end and NOS as a means for socioscientific decision making involve decision making. I highlight the importance of guiding students to practice making decisions on what views of NOS to acquire and practice using their NOS views to make decisions on socioscientific issues. I start by highlighting a set of empirical studies that has attempted to delineate the potential role of NOS in socioscientific decision making.

Zeidler et al. (2002) raised the role of one's NOS understandings and their influence on one's decision making with respect to socioscientific issues. The researchers explored the relationship between high school and college students' views of NOS and their reactions to evidence that challenged their beliefs about socioscientific issues. The researchers observed a complex and diverse range of reactions. Zeidler et al. identified only a few visible instances where students' views of NOS were reflected in making judgments involving moral issues in science. The researchers suggested that science teachers engage their students in reflective thinking on socioscientific issues, challenge their students' moral and ethical beliefs, and explicitly teach them NOS.

Despite the fact that Zeidler et al. found a few students whose views of NOS were reflected in their judgments on socioscientific issues, in another study conducted by Bell and Lederman (2003), the participants did not show similar patterns. Bell and Lederman attempted to evaluate the relationship between a group of faculty members' views of NOS and the types of decisions they made regarding certain science and technology based issues. The researchers also tried to understand the factors and reasoning used by the participants in their decision making. By focusing mainly on collecting and analyzing qualitative data, these researchers reported that regardless of what views of NOS the participants had, they based their decision making on personal, moral, ethical and sociopolitical values rather than on their NOS views. Nevertheless, Bell and Lederman set forth the following claim:

> [E]ven if the nature of science is not typically used in decision making, the science education community may decide that it *should* be. After all, it appears intuitive that knowledge about science would be helpful in deciding science and technology based issues if, as students, they were taught to apply current understandings of the nature of science to their decision making. (Bell & Lederman, 2003, p. 370)

The above excerpt shows that Bell and Lederman regard the role of NOS understandings in socioscientific decision making very highly. They wanted to focus on NOS and explicitly guide learners to use their NOS understandings in making decisions on socioscientific issues. The participants in their study showed patterns of decision making based on moral, ethical, personal and sociopolitical values rather than NOS views. By focusing on NOS, Bell and Lederman might have been assuming that NOS understandings could influence the personal, moral, ethical and sociopolitical values of the learner.

In another study that focused on socioscientific decision making, Sadler et al. (2004) explored how high school students interpreted and evaluated conflicting evidence regarding a socioscientific issue about global warming. The researchers found that the global warming issue effectively engaged students to investigate their views related to certain aspects of NOS. The participants showed a range of diverse views related to the social embeddedness of science as well as to the tentative and empirical aspects of NOS. The researchers also identified three ways in which students reasoned about socioscientific issues: (1) viewing as the most convincing position the one that is closely related to their background beliefs, (2) making evaluative judgments based on predicted personal relevance, and (3) dichotomizing between personal beliefs and scientific knowledge. Sadler et al. argued that science teachers need training so that they can effectively integrate NOS and socioscientific decision making. They claimed that teachers need to be able to transform socioscientific issues in media into learning opportunities, a task which demands that teachers have an understanding of scientific content, assumptions held by students, reasoning patterns of students and moral development trends. They argued:

> [W]e are not implying that teachers should try to change the decisions students make; however, teachers should encourage students to integrate scientific knowledge into their decision making processes. Unfortunately, research in this area and practical suggestions for teachers trying to accomplish this are sparse. Science education needs the development of a research program to investigate the many factors that influence socioscientific decision making and their implications for education. (Sadler et al., 2004, p. 404)

Sadler and Zeidler (2005) also investigated the informal reasoning of college students related to genetic engineering scenarios. In particular, they explored the extent to which the participants integrated several factors such as personal experiences, morality, emotive and social considerations into overall patterns of informal reasoning. In resolving genetic engineering dilemmas, the participants demonstrated reason-based, care-based and intuitive-based patterns of informal reasoning, along with moral considerations, and frequently integrated these patterns of reasoning when making decisions. The researchers argued that

> socioscientific decision making is a fundamentally different task than evaluating the merits of a scientific theory. A scientifically literate individual should have aptitudes in both, but the former situation involves normative judgments that may require emotive considerations and personal values, whereas the latter situation should entail evidentiary assessments. (Sadler & Zeidler, 2005, pp. 130-131)

In a similar study, Callahan (2009) utilized qualitative and quantitative methods to explore the impact of a socioscientific issues based curriculum on the NOS understandings of high school biology students. The duration of the intervention was one semester. The researcher reported that students' views did not change greatly over the course of the study and argued that students might have benefited from explicit NOS teaching in the course of the instruction.

Liu, Lin, and Tsai (2011) reported a relationship between scientific epistemological views (SEVs) and reasoning processes in socioscientific decision making. Their sample consisted of 177 first year college students from three public universities in southern Taiwan. The students were asked to fill in questionnaires that had quantitative and qualitative components. The researchers reported that tentativeness and creativity in science were two components of SEVs of students that were directly manifested in socioscientific decision making. Similar findings were reported by Schommer-Aikins and Hutter (2002), who found that adults who had an understanding of knowledge being tentative were more likely to take positions on multiple perspectives when making decisions on socioscientific issues.

Finally, Khishfe (2012) explored the relationship between explicit and reflective NOS instruction and students' decision making on genetically modified food. This researcher conducted a quasi-experimental study involving ninth grade students in four sections at the same school. A treatment group composed of an honors class and a regular class received instruction in genetic engineering and NOS. The students in this group were also taught how to apply NOS aspects as they formulated arguments and engaged in decision making on the specific issue that they were dealing with. A comparison group composed of an honors class and a regular class received instruction on genetic engineering and how to engage in arguments and make decisions on the socioscientific issue in question. Khishfe reported positive results. More participants in the treatment group than in the comparison group based their decision making on some of the NOS aspects that they had learned.

The science education community has not yet identified the extent to which NOS is central for socioscientific decision making. There is a need for more research in different contexts in order to arrive at more solid conclusions. Moreover, there is a need for further intervention studies that can delineate the impact of informed understandings of NOS on learners' socioscientific decision making.

Nevertheless, the present literature seems to suggest that learners' NOS understandings are at least significant for contributing to socioscientific decision making. In addition, Khishfe's (2012) study supports the claim that learners need to be guided to make connections between their NOS understandings and the decisions they make on socioscientific issues. Her study provided evidence that the NOS-related ideas that students learned influenced their decision making factors. From such a perspective NOS could be considered a *means* for making decisions on socioscientific issues. Indeed calling it *a means* rather than *the means* might highlight the importance of other factors (such as emotive and personal values [Sadler & Zeidler, 2005]) that students use in socioscientific decision making.

The focus on *decision making* in both NOS as a means for socioscientific decision making and NOS as an educational end is crucial. While the role of decision making is clear for the former, it is less so for the latter. Taking into consideration that the substantive content of NOS is itself complex, diverse and contested, learners would need to make decisions about what views of NOS to acquire. Despite the fact that the competing views of NOS with their philosophical sophistication might be irrelevant to K-12 instruction (Smith et al., 1997), my position, as was evident in the previous chapter, is that the irrelevancy does not justify the exemption of students from engaging in and developing critical thinking about NOS. School students could at least be encouraged to develop a mindset in order to recognize that there are indeed different views of NOS. Developing such a mindset might entail practicing judgments on NOS views, no matter how trivial these judgments might seem to us. Consequently, developing NOS understandings (NOS as an educational end) would involve decision making because learners would need to make decisions about their NOS views.

As an example to illustrate the role of decision making in both NOS as a means for socioscientific decision making and NOS as an educational end, consider a hypothetical scenario where a natural healer on a TV advertisement program reports her observation that when a patient struggling with cancer used her natural herbal products, the patient's symptoms disappeared altogether. The task of a learner is to evaluate the extent to which the observation reported by this natural healer is believable. In this situation the learner needs to use her understanding of scientific observations and of drawing causal conclusions based upon them in order to engage in the given task. She also needs to consider the difference between correlation and causation. Her understandings of scientific observation, correlation and causation act here as a *means* for making decisions related to the task. Nonetheless, as a prerequisite, the learner also needs to develop *critically* her understandings of scientific observation, correlation and causation; in other words she needs to engage in critical thinking *about* scientific observation, correlation and causation. Hence, she needs to be guided to examine critically *criteria* for observational competency and how causation is inferred (Ennis, 1996a; Norris, 1984). My proposal would entail, therefore, guiding the learner to think *about* scientific observations, correlation and causation by giving her the chance to examine critically the criteria for observational competency, correlation and causation, and then guiding the learner to *apply* her understanding of scientific observation, correlation and causation to make a decision about the extent to which the observation reported by the natural healer is believable and, if so, whether causation could be inferred from it. Details on how to guide the learner will be provided in Chapters 4 and 6.

In sum, then, the literature reviewed shows that learners do not automatically apply their NOS understandings in socioscientific decision making. There is supporting evidence for the importance of addressing NOS as a means for socioscientific decision making in addition to NOS as an educational end. Unfortunately, as discussed previously, consensus frameworks of NOS in school science are not clear on this distinction; moreover, they provide little support for the science educator to guide her learners to make connections between their NOS understandings and decisions regarding socioscientific issues. Hence, a more precise purpose is needed for NOS in school science that explicitly addresses both NOS as an educational end and NOS as a means for socioscientific decision making.

In addition to illustrating the importance of addressing NOS both as an educational end and as a means for socioscientific decision making, the example illustrated in this section also shows the importance of addressing the *critical stance* that is required in both cases. Future citizens need to be trained to think *critically about* NOS and *critically with* NOS. I move next into discussing the importance of critical thinking in more depth.

Critical Thinking as a Foundational Pillar of NOS in School Science

In this section I evaluate *critical thinking* as a potential candidate for a foundational pillar of NOS in school science. Specifically, based on a review of a representative literature of the field of critical thinking in philosophy of education, I argue that there are at least three good reasons that could support critical thinking to be a foundational pillar: (1) critical thinking is fundamental to good decision making, (2) critical thinking has some potential in helping learners make good decisions particularly in what views of NOS to acquire and what judgments on socioscientific issues to make, and (3) critical thinking is sensitive to context. Finally, I offer a fourth argument in support of my proposal: critical thinking provides a process-oriented focus for NOS in school science, thus portraying a more authentic image of the substantive content of NOS and the process of its development.

How fundamental is critical thinking to decision making? Whether an individual is to make a decision on a socioscientific issue or a decision about what views of NOS to adopt, she has to attempt to produce a certain outcome as a result of thinking. This outcome could have a reasoning component, an action component, or both. Ennis (1989, 1996a) defines critical thinking as “reasonable reflective thinking focused on deciding what to believe or do” (1989, p. 4).

Lipman (2003) also highlights the significance of producing an outcome in his definition of critical thinking. He claims:

> Critical thinking is applied thinking. Therefore, it is not just process – it seeks to develop a product. This involves more than attaining understanding: It means producing something, said, made, or done. It involves using knowledge to bring about reasonable change. Minimally, the product is a judgment; maximally, it is putting that judgment into practice. (Lipman, 2003, p. 211)

Siegel (1988) argues that in order for a person to be engaged in critical thinking, reasonable thinking should be accompanied by reasonable act. He claims:

> To be a critical thinker is to be appropriately moved by reasons. To be a rational person is to believe and act on the basis of reasons. There is then a deep conceptual connection, by the way of the notion of reasons, between critical thinkers and rational persons. (Siegel, 1988, p. 32)

But how fundamental is critical thinking in general and in decision making in particular? Siegel's (1988) argument above emphasizes the connection between critical thinking and rationality. He regards critical thinking not only as central in educational affairs but also as a "fundamental educational ideal" (p. 2). Siegel explores four main considerations to justify critical thinking as an educational ideal: (1) a moral obligation to respect students as persons, (2) preparation of students for the successful management of adult life, (3) the need of initiation into the rational traditions, and (4) preparing democratic citizens.

Siegel argues that rationality and critical thinking are universal. From this perspective, critical thinking could be regarded as fundamental for socioscientific decision making as well as for deciding what views of NOS to acquire. However, several authors have criticized the universality of critical thinking. Doddington (2007) has drawn upon alternative views of how we should conceive of being in this world to argue that we need to move away from the idea that critical thinking and rationality are the main indicators of good thinking. To her, sense, perception, and embodied personal thinking ought not be neglected in the curriculum; for while they cannot be subsumed under critical thinking, they are significant for respecting the whole person. Doddington writes:

> They [alternative views] begin to imply that alongside the undeniably useful approach to life and the world that is embraced by critical thinking, there are equally valuable, or even prior, elements of personhood and a distinctly human relationship to the world that needs conceptualising if we are to fully understand what it is to respect and therefore to educate persons. (Doddington, 2007, p. 451)

Sense, *perception* and *embodied personal thinking,* as set forth by Doddington, are valuable assets to consider in the science classroom; a good science teacher needs to take a holistic approach in dealing with her students. Doddington's argument makes sense: "A view that over-valorises critical thinking at the expense of other aspects of humanity results in a reduced and therefore distorting view of what we should value and cherish about personhood through education" (p. 458). However, *sense*, *perception* and *embodied personal thinking* cannot have a status that is *equally valuable* or *prior* to that of critical thinking if we care to provide an authentic image of how the substantive content of NOS develops. This objection is aligned with Siegel's argument for critical thinking as a means of introducing students to rational traditions. I showed in the previous chapter that critical thinking is the main mechanism used in the philosophical debates on NOS and the main tool through which philosophers produce their respective positions regarding NOS. This means that rationality is a fundamental criterion in the discourse involving NOS. Critical thinking ought to be the major part of a NOS lesson if learners are to be provided with authentic learning experiences.

More radical criticisms against the critical thinking movement have been provided by Peters (2007). Based upon the writings of Nietzsche, Wittgenstein and Heidegger, as well as on critical theory and French poststructuralist philosophy, Peters has criticized the critical thinking movement for treating thinking ahistorically and focusing on universal processes of logic and reasoning. Peters has provided historical and philosophical accounts of thinking and reasoning. He has argued for "pluralized" kinds of thinking and styles of reasoning.

While for Peters (2007) culture transcends rationality, for Siegel (2007) rationality is culture-free. Siegel (2007) analyzes whether rationality could differ from culture to culture. He provides a critique of Melzer, Weinberger, and Zinman's (1998) definition of multiculturalism, which is based on the Nietzschean denial of the possibility of universal truth. Siegel finds their definition problematic because they build a “contentious epistemological thesis” (p. 205) for multiculturalism. He argues that “it would be impossible to be a multiculturalist and at the same time be a fan of such truth” (p. 205), highlighting that multiculturalism is a moral political matter rather than an epistemological one. He claims:

> We should be doubtful of the claims that cultures have their own rationalities, that rationality is relative to culture, and that a commitment to multiculturalism requires a commitment to any such claims about rationality. Cultures are diverse and divergent, but rationality is not. And in any case, such claims as these concerning multiculturalism and rationality cannot themselves be rationally established if it is. (Siegel, 2007, pp. 217, 218)

Some contemporary literature, such as Doddington’s and Peters’ work, has highlighted the existence of different kinds of thinking and has challenged how fundamental critical thinking might be in education. If authentic learning experiences are important in education, then educators have no other choice but to consider critical thinking as fundamental in addressing NOS because critical thinking is itself fundamental in the development of the substantive content of NOS. Critical thinking is a fundamental mechanism of knowledge generation in various academic disciplines. Let’s also not forget that the knowledge generated by the critics of the critical thinking movement is also based on critical thinking.

How can good decision making be manifested through critical thinking? This question is significant for the following reason: If critical thinking is to be considered a foundational pillar for NOS in school science, then it should have the potential to help learners to make *good* decisions about what views of NOS to adopt as well as to make *good* judgments about socioscientific issues.

Lipman (2003) distinguishes between the making of judgments and the making of good judgments. To him, good judgment needs to be based on good criteria. But how does one produce a repertoire of good criteria? How does one come to differentiate between criteria that are good and those that are not? What are these criteria anyway? It is exactly here that the role of NOS instruction in school science becomes critical. If we acknowledge that there are good criteria that should guide a citizen to make good decisions about NOS views and good judgments about socioscientific issues, then NOS in school science should help students to develop good criteria in the first place. Lipman (2003) claims:

> [I]n my opinion, we will not be able to get students to engage in better thinking unless we teach them to employ criteria and standards by means of which they can assess their thinking for themselves. (Lipman, 2003, p. 75)

These criteria cannot be clear-cut rules that a student may acquire as a result of NOS instruction. If these criteria could be reduced to such clear-cut rules, then Lipman does not have to be concerned with quality of judgment because judgment would then involve nothing more than mechanically applying these rules to different contexts. Lipman's criteria will be discussed in more detail in Chapter 4.

Just as Lipman raises the significance of *criteria* in making good judgments, Siegel (1988) highlights the notion of *principles* to argue that in order to look for reasons, one should commit to principles. Siegel finds a deep connection between reasons and principles, and as a result he claims that "critical thinking is principled thinking" (p. 34). Next, he introduces Israel Scheffler's notion that consistency has a deep connection with reasons and principles. He argues:

> Because of this connection between reasons and principles, critical thinking is principled thinking; because principles involve consistency, critical thinking is impartial, consistent, and non-arbitrary, and the critical thinker both thinks and acts in accordance with, and values, consistency, fairness, and impartiality of judgment and action. Principled, critical judgment, in its rejection of arbitrariness, inconsistency, and partiality, thus presupposes a recognition of the binding force of standards, taken to be universal and objective, in accordance with which judgments are to be made. (Siegel, 1988, p. 34)

Thus, in order for a citizen to be principled thinker, she should be consistent in her judgments. Principled thinking, according to Siegel, requires two conditions. First, this citizen should be able to assess properly her reasons and the principles behind those reasons. Siegel argues that it is essential for the critical thinker to "have a good understanding of, and the ability to utilize, principles governing the assessment of reasons" (p. 34) as well as an understanding of epistemology (nature of reasons, warrant and justification). Second, the citizen should have a critical attitude or a "well-developed disposition to engage in reason assessment" (p. 39). Siegel highlights some of these critical attitudes such as caring about reason and its use, valuing intellectual honesty, objectivity and impartiality.

Siegel (1980, 1988) considers critical thinking to be a regulative ideal, meaning that it sets standards for educational proposals to meet. Siegel (1988) writes:

> To say that critical thinking is a regulative educational ideal is to say that the notion of critical thinking, or its constitutive components, can and should be used as a basis by which to judge the desirability and justifiability of various features of or proposals of the educational enterprise. (Siegel, 1988, p. 47)

However, if critical thinking is regulative, then how does one explain the fact that there is so much controversy over NOS, given that philosophers of science and science educators employ, to use Siegel's words, "universal" and "objective" standards in their thinking in adjudicating alternatives and making choices? This question can be addressed from more than one viewpoint. First, Siegel (1988) distinguishes between critical thinking and the critical thinker. While critical thinking is argued as an educational ideal, a critical thinker is a person who is "moved by reasons" (1988, p. 32) and is "a rational actor" (1988, p. 41). Siegel takes an internalist perspective (1988, p. 153) in his philosophy of action, meaning that he is concerned with inquiring whether the *agent* (critical thinker) has good reasons for performing the action rather than whether there are good reasons for performing the action. Consequently, it could be argued that Siegel may attribute the various and contending NOS viewpoints to the abilities of the various scholars to provide good reasons. In other words, critical thinking is an ideal and humans apply it fallibly.

From another perspective, if one takes a historical approach and thinks about the different traditions in philosophy of science that have existed and do exist, it might be difficult to adopt an internalist appraisal. Siegel is well aware that rational traditions are evolutionary rather than static. He thus finds a tension between the fact that principles evolve and the requirement for them to be universal and impartial. He attempts to resolve this tension by arguing that

> [p]rinciples embody rationality and define and assess reasons in a tradition at a time. As the tradition evolves, so do the principles which define and assess reasons. . . As time goes on, the qualities which secure the legitimacy and force of reasons in a tradition may change, for the principles which define reasons and determine their force may change, but rationality remains the same – judgment and action in accord with reasons, as determined by principles (which are themselves justified) crystallized at a time in a rational tradition. (Siegel, 1988, p. 135)

Consequently, a particular tradition in the philosophy of science might be based on particular principles that are the bases for defining reasons and assessing them at a particular time. Yet, when the tradition evolves with time so do the principles and reasons. However, what remains constant is rationality itself.

Ennis's (e.g., 1996a, 1996b) work on critical thinking focusing on lists of critical thinking abilities and dispositions is more elaborate and concrete from a pedagogical standpoint than Lipman's or Siegel's. Ennis (1996b) argues that both critical thinking abilities and critical thinking dispositions need to be incorporated in the goals of critical thinking instruction so that one can produce good judgments. Ennis (1996a) has developed a general guide to critical thinking (referred to as the FRISCO) that can provide the learner with a useful checklist whether in judging an idea or trying to develop a new one. The elements of this guide are: *focus* (asking oneself questions such as what is going on and what it is all about); *reasons* (knowing the reasons offered in support of a conclusion and deciding whether they are acceptable); *inference* (deciding the extent to which the reason supports the conclusion); *situation* (understanding the broad context which involves the physical and social environment as well as the values and beliefs of stakeholders involved); *clarity* (being clear in what one says and asking for clarity); and *overview* (monitoring one's own thinking and checking what one has discovered, decided, inferred, considered and learned). Ennis (1996a) divides critical thinking into several concepts and provides lists of criteria for each of these concepts. Some of the concepts are divided into sub-concepts. A list of Ennis's critical thinking concepts can be found in Appendix A, and criteria for some of these concepts can be found in Appendices B to E. As far as the critical thinking dispositions are concerned, Ennis (1996b) has developed a set of three dispositions that underlie the critical thinking abilities, namely "(1) to 'get it right' to the extent possible, (2) to represent a position honestly and clearly, and (3) to care about the dignity and worth of every person" (Ennis, 1996b, pp. 170-171). Each of these dispositions is further divided into subcategories.

Paul (1994) differentiates between critical thinking in the weak sense and in the strong sense. A critical thinker in the weak sense thinks critically about positions other than her own. A critical thinker in the strong sense sees the picture holistically; she thinks critically about her own position, arguments and worldviews as well as those of others. Accordingly, critical thinking in the strong sense is "inescapably connected with discovering both that one thinks within 'systems' and that one continually needs to strive to transcend any given 'system' in which one is presently thinking" (p. 182). Paul thus argues that a critical thinker is someone who not only is aware that different worldviews exist but also has a deep knowledge of herself in that she is committed to monitor her own thinking with the purpose of minimizing the "pathologies of thought" (p. 183). From his perspective, engaging in dialogue with others who have different worldviews and cultural backgrounds is crucial for critical thinking.

Bailin, Case, Coombs, and Daniels (1999) consider critical thinking to be a normative enterprise, in which thinking quality rather than thinking processes distinguishes critical from uncritical thinking. They view competence in critical thinking in terms of "intellectual resources" (p. 286) rather than of lists of attributes that critical thinkers have. They use the term *intellectual resources* to mean the following: "background knowledge, knowledge of critical thinking standards, possession of critical concepts, knowledge of strategies or heuristics useful in thinking critically, and certain habits of mind" (p. 286). The authors criticize previous scholarly work which has produced lists of skills of what a critical thinker should be able to do, for “such lists imply nothing about the psychological states, capacities or processes that enable critical thinkers to have the requisite accomplishments, and nothing about the kinds of instructional procedures that are likely to be efficacious in bringing them about” (p. 290). The authors argue that students must be given opportunities to practice using a variety of intellectual resources in making good judgments.

The literature reviewed in this section shows that critical thinking has some potential in helping learners to make good decisions about what views of NOS to adopt, as well as to make good judgments about socioscientific issues. This scholarly work reveals that critical thinking has certain attributes the understandings and use of which could enable the critical thinker to produce good decisions. In a very broad sense, Lipman’s *criteria*, Siegel’s *principles,* Ennis’s *critical thinking skills and dispositions* and Bailin et al.’s *intellectual resources* offer the potential for operationalizing critical thinking. Ennis’s work, however, seems to be more specific than the others, and pedagogically more concrete, as he delineates critical thinking in terms of concepts and provides lists of criteria for these concepts. More will be discussed about Ennis’s critical thinking theory in Chapter 4. Good decisions about NOS views and good judgments about socioscientific issues require an understanding of these concepts and criteria as well as the ability to apply them in decision making. Future citizens need to be given chances to develop understandings and to engage in such practices. It would make more sense educationally to bring critical thinking into the foreground of school NOS, and to provide future citizens with learning opportunities in which they could examine these criteria and practice using them in order to make good decisions regarding their views of NOS as well as to make good decisions about socioscientific issues.

How can critical thinking manifest itself in the distinction between NOS as an educational end and NOS as a means for socioscientific decision making? This question is significant for the following reason: If critical thinking is sensitive to context, then learners need to be guided to think critically in both the contexts of NOS as an educational end and NOS as a means for socioscientific decision making.

Ennis (1964) considers critical thinking to be a general ability. A critical thinker is involved in "the correct assessing of statements" (p. 599), being proficient in making judgments on whether

1. A statement follows from the premises.
2. Something is an assumption.
3. An observation statement is reliable.
4. A simple generalization is warranted.
5. A hypothesis is warranted.
6. A theory is warranted.
7. An argument depends on an ambiguity.
8. A statement is overvague or overspecific.
9. An alleged authority is reliable. (Ennis, 1964, pp. 599-600)

McPeck (1981) takes a radically different stance. He considers critical thinking to be subject specific and dependent on a thorough understanding of the content and epistemology of the discipline. Thinking is always about something; that something may range from being very specific to very general. McPeck (1990) argues that "there can be no one general skill or limited set of skills (including formal logic) which could do justice to this wide variety of objects" (p. 11). Thus, in McPeck's view, critical thinking is learned through specific contexts and cannot be transferred to new contexts.

The subject specificity or neutrality of critical thinking has been long debated between Ennis and McPeck. In a more recent work, Ennis (1989) differentiates among three versions of subject specificity: domain, epistemological and conceptual. He argues that all three of these versions suffer from the vagueness of their basic concepts of "domain," "field" and "subject" respectively. McPeck (1990) responds to Ennis (1989) by arguing that the circumstances of how these terms are used in context would determine their meaning. He criticizes Ennis for presupposing "some fixed meaning of the concepts *subject*, *domain*, and *field* such that their use is (or can be) always clear, definitive, or exhaustive" (p. 10). Ennis (1990) responds that the vagueness of these terms poses a problem when subject specificity serves as the basis for prediction or application. He also argues for the existence of general critical thinking skills and dispositions, and claims that when an ability is applied to different domains it becomes a general ability. For Ennis, then, critical thinking is sensitive to context yet transferrable across domains, and because it can be applied to different domains, it becomes a general ability.

Lipman (2003) refutes McPeck's argument that critical thinking must be subject specific. He claims that McPeck has ignored the counter instance of philosophy:

> That philosophy and logic do exist and that they are normative disciplines concerned with specifying what excellence in thinking ought to be – these facts are in themselves a refutation of McPeck's rejection of the notion that there is a discipline specifically devoted to the teaching of thinking as an autonomous activity. (Lipman, 2003, p. 44)

Siegel (1988), on the other hand, argues that subject-neutral logical principles and subject-specific principles are equally essential in critical thinking. In critiquing McPeck's work, Siegel (1988) writes:

> McPeck is, I think, half right. He is right that logical knowledge regarding the nature of assumptions will not by itself enable students to identify assumptions in all contexts. Specific knowledge of the subject matter at hand is typically required as well. But by the same token, the specific knowledge by itself will equally fail to enable students – let them know as well as you like about the specific subject under consideration, they will not be able to identify assumptions in arguments in that area if they do not know what an assumption is. Thus logical knowledge concerning the nature of assumptions, and subject-specific knowledge, are both necessary; neither is by itself sufficient. (Siegel, 1988, p. 21)

Based on a review of the literature, Norris (1985), working in the area of testing, sets forth two reasons for believing that critical thinking is sensitive to context. First, one's inferences depend on the concept, background assumptions, and level of sophistication related to a task. Norris argues that inferences that do not agree with those sanctioned by a test do not necessarily indicate a critical thinking deficiency. He concludes that the assessment of competency in critical thinking must take into consideration the context in which the thinking is performed. Second, Norris claims that empirical evidence shows that context can affect the quality of one's performance in critical thinking. Despite the fact that, in deductive logic, the question of whether or not the conclusion follows from a particular reason is dependent on the structure of reasoning rather than the content, people reason better deductively when the context is thematic or related to personal experience.

Finally, Bailin (2002) also argues that critical thinking is sensitive to context. She claims that *intellectual resources* are needed to deal with challenges arising in different contexts. She argues:

> The question is not whether a certain mental ability transfers to a variety of domains. It is, rather, what constellation of resources is required in particular contexts in response to particular challenges and what the range of application is for particular resources. Thus the issue of domain specificity versus generalizability, with its attendant problems concerning the nature of skills and domain delineation, does not arise for my account. (Bailin, 2002, pp. 368-369)

The literature reviewed in this section shows that critical thinking is context sensitive. Accordingly, it is necessary to engage students in critical thinking in order for them to practice its use in the contexts of both NOS as an educational end and NOS as a means for socioscientific decision making. It cannot be assumed that students will be able to show evidence of good critical thinking in both contexts if they have not been given the chance to practice critical thinking in both these contexts.

Focusing on process. The science education community is well aware of the undesired consequences of teaching scientific knowledge without regard for the processes by which that knowledge is produced. For instance, detaching scientific content knowledge from the processes promotes a naïve view of the nature of scientific inquiry resulting in an image of science as a collection of isolated facts (Schwab, 1962). As a remedy, the science education community has reached a broad agreement on the importance and role of inquiry in the teaching and learning of science (e.g., Krajcik et al., 1998; NRC, 1996; Roth, 1995; Schwab, 1962; Tamir, 1983). The results of a meta-analysis conducted by Shymansky, Hedges, and Woodworth (1990) suggested that the inquiry-based science curricula developed during the sixties and seventies in the United States were generally more effective in improving student performance on cognitive measures and in raising attitudes about science than were traditional textbook-based programs that emphasized knowledge of scientific facts, laws, theories and applications. In a more recent study that aimed at analyzing and synthesizing findings from 138 studies on the impact of inquiry science instruction on K-12 student outcomes, Minner, Jurist Levy, and Century (2010) reported that teaching strategies that actively engage students in scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques.

As part of orienting school science teaching and learning around inquiry, the hope of the science education community is that students will develop understandings of NOS (CMEC, 1997; NRC, 1996, 2012). Ironically, NOS gets addressed in the same way that science educators know leads to undesirable outcomes when scientific content knowledge is taught that way. As discussed in Chapter 2, many science educators keep placing their focus on the substantive NOS content rather than the process of how the substantive NOS content develops. Detaching the substantive NOS content from the process of its development promotes a naïve view of philosophy of science: It portrays an image of NOS as a collection of isolated facts. It also promotes a non-authentic image of the philosophical discourse on NOS and the process of how the substantive NOS content develops.

I suggest that if process-oriented teaching and learning is desirable in school science, then there is no reason why process-oriented teaching and learning should not also be desirable for NOS in school science. The nature of the substantive content of NOS is quite different from that of the substantive content of science. Unlike in the latter, where there is some tendency towards agreement on the substantive content of science, there is less tendency in the philosophy of science towards agreement on the substantive content of NOS. The presence of competing views on NOS supports this claim; it is not surprising given that the work of philosophers of science involves understanding science from *outside* the field of science. If it makes sense to have a process-oriented focus for the teaching and learning of science, it should make even more sense to have a process-oriented focus for the teaching and learning of NOS because of the extensive NOS-related views that define the nature of the substantive content of NOS.

But how can a process-oriented focus for school NOS be developed? If an inquiry-based teaching and learning of the substantive content of NOS is prescribed, more uncertainty than clarity would result, given the vagueness of the construct. Inquiry is an ambiguous term and there are multiple interpretations of it (Minner, Jurist Levy, & Century, 2010; NRC, 2012). This is one reason why the new conceptual framework for K-12 science education standards in the US (NRC, 2012) highlights the importance of engaging students in the practices of science (and engineering) – rather than inquiry.

> Engaging in the practices of science helps students understand how scientific knowledge develops. . . Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview.
>
> The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the

> insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor. (NRC, 2012, pp. 42-43)

The use of the term *practices* rather than *inquiry*, according to the NRC document, is a move away from the ambiguity created in the science education community with respect to the latter term. It is also a move towards minimizing the tendency to reduce scientific practice to a single set of procedures and avoiding the common misconception that there is a single scientific method.

While in general terms the practices of science may be compared with the practices of NOS, there is the need to delineate the latter more specifically. My analysis of the philosophical debates on NOS in the previous chapter has highlighted one dimension of such practices: *Critical thinking* is a major mechanism utilized by scholars engaged in philosophical debates and for creating NOS-related positions. Engaging students in critical thinking about NOS can help them to develop understandings of how the substantive content of NOS develops, as well as to understand the substantive content of NOS itself (assuming that there is explicit reference to it). Certainly this claim is open for empirical research. Yet, at the minimal level, a process-oriented focus of NOS instruction, in general, with critical thinking as a foundational pillar, makes learning of NOS more authentic than an outcome or content-oriented focus.

Such a proposal brings with it a list of challenges in terms of ensuring that teachers are prepared to handle critical thinking. There is some literature that suggests that teachers have difficulties understanding what critical thinking is and how to teach it. In a study that aimed to assess current teaching practices and knowledge of critical thinking among faculty teaching in teacher preparation programs in California, Paul, Elder, and Bartell (1997) reported that 89% of the interviewed faculty members claimed that critical thinking was a primary objective of their instruction. However, only 19% gave a clear explanation of what critical thinking is, and only 9% were teaching critical thinking on a typical day in class. Most faculty members had not thought much about critical thinking and had no formal professional development in it. These faculty members also had difficulty explaining how they would teach it. The very few faculty members who had systematically studied critical thinking and who had participated in professional development activities on critical thinking demonstrated a much higher ability to explain the concept and to integrate strategies conducive to it in their teaching. Similar findings were reported by Bataineh and Alazzi (2009) in a study that explored secondary school social studies teachers' perspectives of critical thinking in Jordan. The researchers reported that the teachers were not familiar with the definition and teaching strategies of critical thinking. Consequently, if critical thinking is moved into the foreground of NOS instruction, as I have proposed, then it will be essential that science teachers are provided with ample support to reflect on their understandings, as well as with strategies to teach critical thinking with the purpose of developing more adequate conceptions, skills and attitudes.

Refocusing the discussion. Critical thinking is a potential candidate as a foundational pillar of NOS in school science. Based on the discussions in the previous sections, there are at least four justifications for such a proposal: (1)

critical thinking is fundamental to decision making, which is needed in approaching NOS both as an educational end and as a means for socioscientific decision making, (2) critical thinking has some potential in helping learners make good decisions about what views of NOS to acquire, as well as to make good judgments on socioscientific issues, (3) critical thinking is sensitive to context, and (4) critical thinking provides a process-oriented focus for NOS in school science, thus portraying a more authentic image of the substantive content of NOS and the process of its development.

Indeed, my proposal that critical thinking is a foundational pillar changes the focus of NOS in school science. In Chapter 2, I argued that consensus frameworks of NOS situate the substantive content of NOS in the foreground of NOS instruction. My proposal brings critical thinking into the foreground of school NOS, moving the substantive NOS content into the background. Rather than working towards developing adequate understandings of NOS-related ideas among students, the focus will be placed on the *process* as learners are guided to (1) practice making judgments on what views of NOS to adopt, or at the minimal level develop a mindset enabling them to make informed judgments on what views of NOS to adopt; and (2) practice making decisions on socioscientific issues.

I now turn into the fourth part of this chapter. In this part I highlight the need to place school NOS on a developmental pathway.

A Developmental Pathway for School NOS

In this section I review the literature of NOS in school science to show that there are certain developmental aspects that some researchers have attended to, but that their suggestions have not been transformed into research agendas. I argue for the need to situate school NOS across a developmental pathway.

Several researchers have empirically demonstrated the possibility of a developmental pattern of students' views of NOS. Solomon, Scott, and Duveen (1996) studied British students' understandings of several aspects of NOS. Their sample was composed of Year 10 students aged 14 and 15, drawn from schools in ten different locations. The researchers also observed seven classes from this sample for over a year. They developed a questionnaire with questions related to several aspects of NOS. Particularly, the researchers were interested in how the students would evaluate the terms *theory* and *evidence* as well as the relationship between them. The same questionnaire was also given to Year 8 students aged 12-13, and to students aged 17-18, to study the progression of students' ideas of NOS. Solomon et al. found that Year 10 students were significantly more likely than Year 8 students to answer that scientists know what is expected to happen before conducting a particular research study. The students aged 17-18 were beyond the age of compulsory education and had chosen to take a science course. Compared to Year 8 and 10 students, these students demonstrated a good understanding of scientific investigation as a search for explanation, an increase in understanding that theory is dependent on evidence, and an increase in understanding of the role of imagination for scientists to be able to make sound predictions of experimental outcomes.

In Zeidler et al.'s (2002) investigation, high school and pre-service science education students responded to questionnaires which elucidated their NOS views as well as their convictions on a certain socioscientific issue. The researchers reported notable differences between the responses of high school and college students. The views of students on the tentative aspect of NOS, for instance, were quite diverse and ranged from highlighting the importance of falsification to recognizing the social use of scientific theories. For college students, possessing potential problem solving capabilities was also an important criterion under the tentative aspect of NOS. In addition, unlike high school students, college students' views showed evidence of conflation among various activities of science and opinion, integration of social factors in discussing ethical issues, and fusion of religious values with scientific epistemologies when they reasoned about the use of animals for medical or consumer research.

Khishfe (2008) investigated the development of seventh graders' NOS views, particularly those regarding the tentative, empirical, inferential and creative aspects of NOS. The study took place in the context of inquiry-based activities over the course of a three-month-period, during which time students engaged in explicit and reflective discussions on the target aspects of NOS. Students' views on these aspects were identified before, during and after the intervention using an open-ended questionnaire and follow up interviews. Khishfe's analysis showed certain patterns of gradual development in students' views. She found that students' naïve views became "intermediary" over time, and that the intermediary ones became informed, suggesting that students' views developed on a continuum in a progressive manner. She concluded that ''the intermediary forms supports the view of an evolving developmental model and can contribute to an understanding of the process involved in the development of students' views of NOS from naive to more informed'' (p. 491). She raised the importance of further studies that directly address developmental issues.

Yacoubian and BouJaoude (2010) investigated the effect of explicit and reflective discussions on Grade 6 students' views of the tentative, empirical, subjective and social aspects of NOS. The context of the study was inquiry-based laboratory activities. We identified five challenges that the students faced in their attempts to change their NOS views over the course of the 4-month-long intervention. These challenges, which were identified by systematically analyzing multiple data sources, were (1) viewing science as a relative enterprise, (2) differentiating among the components of inquiry, (3) realizing the possibility of different explanations for the same phenomenon, (4) viewing scientific experiments as tools rather than goals of science, and (5) viewing communication as a tool in the construction of scientific knowledge, and understanding the relation between personal learning of science and construction of scientific knowledge. We argued that these challenges could be helpful in future research for determining how students' views of NOS change over time.

The studies reviewed have identified and described certain features that could potentially contribute to a more comprehensive understanding of developmental aspects related to NOS learning. There is certainly a need for similar studies, and there is an urgent need to use these and similar findings to design longitudinal studies with the purpose of systematically analyzing the developmental patterns of students' NOS views and targeting a more comprehensive picture of developmental aspects of NOS. In a recent paper, Abd-El-Khalick (2012b) suggested keeping the focus on general aspects of NOS (e.g., tentative, empirical, subjective aspects among others) but making sure that these aspects are "addressed at increasing levels of depth as learners move along the educational ladder from elementary school to college-level science teacher education programs" (p. 1047). Abd-El-Khalick wants to ensure a developmental approach for the general aspects of NOS that move from the simple to the more complex, from the general to the more specific, and from the unproblematic to the more controversial over the years of formal education. To my knowledge, there are no studies that have attempted to situate NOS instruction in an increasing level of depth with the purpose of systematically analyzing developmental patterns.

One reason for the lack of such studies may be related to the difficulty in determining what should count as "complex" and "specific" NOS understandings, to use Abd-El-Khalick's (2012b) words. The challenge that I highlighted in Chapter 2 related to the consensus frameworks of NOS holds true in this situation as well. Once agreed that students need to explore at some depth the so-called general aspects of NOS, we would expect that the controversies would come to the surface. Consequently, it would be hard to come to an agreement as to whose version or versions of NOS should be considered the desired "complex" and "specific" understanding, unless a decision was made to move the spotlight away from the substantive content of NOS and to focus on the critical thinking process. Doing so would necessitate the creation of a developmental pathway for critical thinking itself.

The new conceptual framework for K-12 science education in the US (NRC, 2012) highlights the notion of learning as a developmental progression. There is a need to develop a research agenda that targets the creation of learning progressions for NOS in school science with critical thinking as the progression unit. Duschl et al. (2007) define learning progressions as "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time" (p. 214).

Developing learning progressions for NOS in school science requires us to determine the desirable knowledge and skills of critical thinking in the context of NOS as a basis for the "complex" learning that we expect high school students to have mastered upon graduation. Research in developmental psychology could provide some directions and might be helpful. Developmental literature could help us to better understand developmental patterns in critical thinking. Upon understanding these patterns, we could situate them in the context of NOS learning and derive testable hypotheses. In Chapter 5, I explore the possibility of learning progressions for NOS in school science in more depth.

In sum, I examined certain developmental factors related to developing NOS understandings that science educators have had as their focus. I highlighted the need to use the findings from these and similar studies, and to design longitudinal studies to explore systematically a more comprehensive picture of how students' NOS views develop. Moreover, I discussed the importance of developing learning progressions for NOS in school science with critical thinking as the progression unit. In the section that follows, I argue that when the proposals set forth in this chapter are realized, it will be legitimate to talk about *NOS curriculum in school science* rather than *NOS-related ideas in school science.*

A NOS Curriculum

Taking into consideration Walker's (2003) and Van den Akker's (2003, 2010) definitions of curriculum, one might easily categorize the three arguments that I have made in this chapter into aspects of their definitions. The first argument, that a more precise purpose for teaching NOS in school science is needed, may present a *rationale* or *purpose* for such a curriculum and could help refine the purpose of NOS in school science. The proposals to place school NOS in critical thinking as well as developmental frames would contribute to creating an *organization* for the purpose and content of the curriculum. Finally, my proposal to place critical thinking in the foreground of school NOS and the substantive NOS content in the background would open the possibility of redefining what to teach under the title of NOS – that is, the *content* of this curriculum. Consequently, a NOS curriculum has the potential capability of bringing together the following: (1) *what* to teach under the title of NOS, (1) *why* to address NOS in school science, and (3) *how* to organize what needs to be addressed under NOS.

I am not proposing a NOS curriculum that is separate from the science curriculum. An adequate NOS curriculum could be created within the latter, as long as the suggestions set forth in this chapter are adequately met. My proposal entails replacing the NOS-related *ideas* in school science with a NOS *curriculum* possessing the characteristics discussed in this chapter. Such a curriculum would have the potential to minimize some of the unintended consequences of the consensus frameworks of NOS in school science that I highlighted in Chapter 2. A NOS curriculum could potentially (1) encourage learners to make connections between their NOS understandings and decisions that they would make regarding socioscientific issues, (2) present a more authentic image of the substantive content of NOS and the process of its development, and (3) be more considerate to the developmental needs of the learners. Such a curriculum is important if we want to prepare scientifically literate citizens who can contribute to democratic decision making.

Thus far I have critiqued consensus frameworks of NOS in school science and have explored the potential of a NOS curriculum with particular characteristics as an alternative to consensus NOS frameworks. In Chapters 4 and 5, I synthesize a framework of NOS in school science built on the proposals set forth in this chapter.

Chapter 4

The Critical Thinking - Nature of Science (CT-NOS) Framework

This chapter elaborates the CT-NOS framework. In order to accomplish this goal, I describe and justify each component of the CT-NOS framework. While doing so, I engage in critical evaluations of Harvey Siegel's, Matthew Lipman's and Robert Ennis's theories of critical thinking and justify my choice of borrowing from Ennis's theory for the CT-NOS framework. I finally demonstrate the applicability of the framework through two examples.

When I propose the CT-NOS framework for addressing NOS in school science, I focus my discussion on student learning. This is a deliberate decision that needs to be justified from the outset of this chapter. Such an approach is not intended to diminish the role of science teachers, textbooks and other educational resources as far as NOS in school science is concerned. The theoretical ideas that form the basis of the CT-NOS framework could be generalized across a wide spectrum of educational products and processes such as curriculum materials, teaching strategies, teaching and learning resources, and textbooks, to name just a few. One could develop sub-frameworks that focus on teacher role, learning environment, assessment and so on, and superimpose them onto the CT-NOS framework in order to make it more comprehensive. This, however, is beyond the scope of this chapter.

The Elements of the CT-NOS Framework

Figure 1 illustrates the components of my proposed CT-NOS framework. A background context in the form of a learning activity reflects a particular NOS theme and a socioscientific issue. The background context acts as a basis upon which learners are invited to think critically *about* NOS and *with* NOS. Critical-thinking-related knowledge, skills and attitudes form the tools that learners utilize as they engage in the learning experience. The framework has two branches and yields two sets of major outcomes (represented as ovals on the figure). The first set of outcomes results from engaging in critical thinking about NOS (i.e., NOS as an educational end). These outcomes are (1) developing NOS understandings and (2) developing critical thinking about NOS. Note that the latter is both an outcome and a process. NOS understandings are those that are derived as a result of engaging in critical thinking about NOS. The implication is that a person having NOS understandings would be able to defend those understandings as a result of her critical thinking about NOS. NOS understandings so defined can be contrasted to views about NOS adopted by a means other than critical thinking and that cannot be defended with reasons.

The second set of outcomes result from engaging in critical thinking with NOS (i.e., NOS as a means for socioscientific decision making). These outcomes are (3) socioscientific decision making and (4) critical thinking with NOS. Once again, critical thinking with NOS is both a process and an outcome. The two branches of the framework are linked to each other; the NOS understandings that learners develop as an outcome of the first branch are used when engaging in a

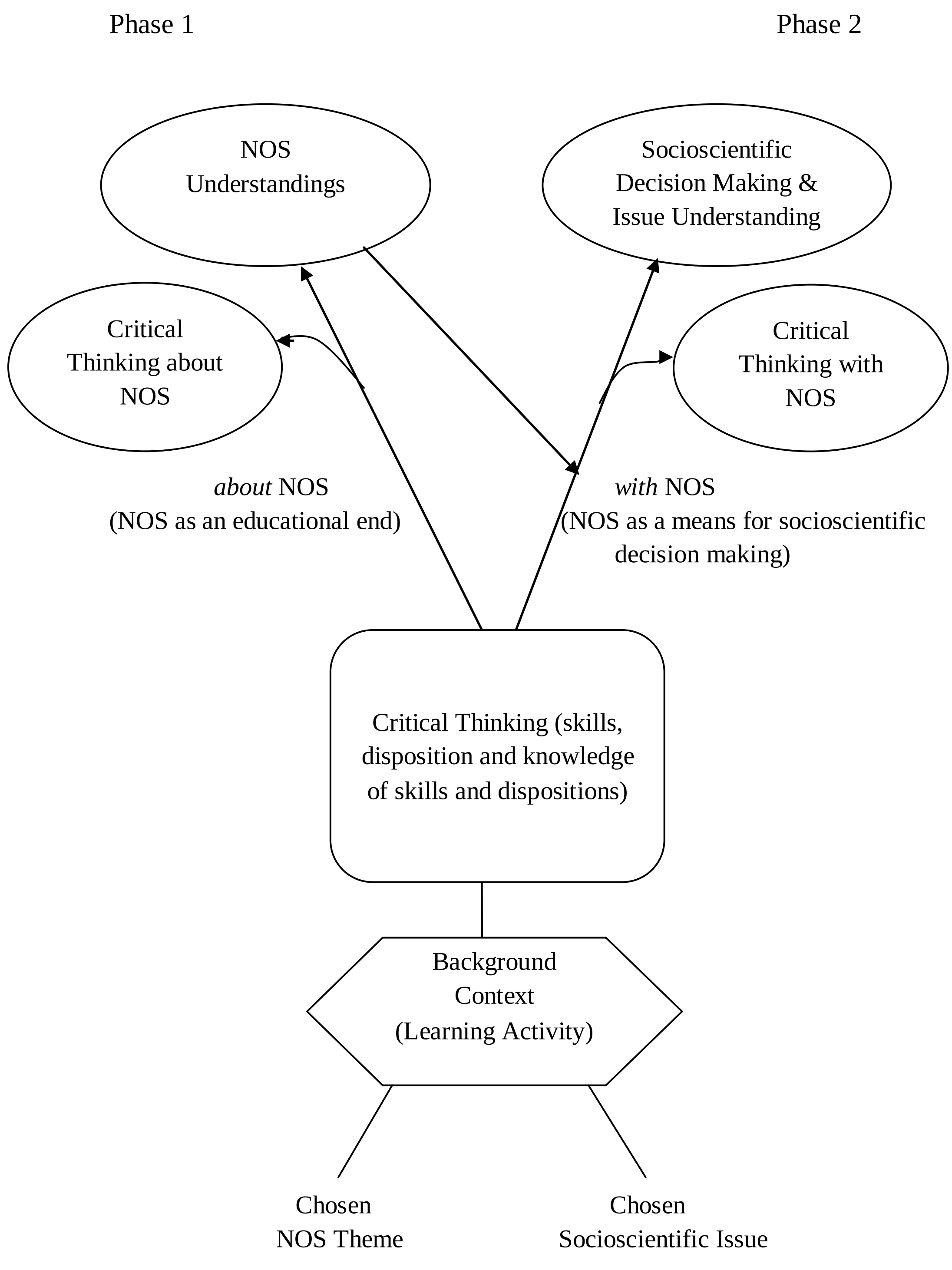

Figure 1. Proposed CT-NOS Framework

process of thinking critically with NOS. In the paragraphs that follow I justify each component of the CT-NOS framework.

Background context. The background context in the form of a learning activity helps to establish the necessary platform on which a discussion of NOS and the socioscientific issue in question will take place. It provides the necessary ingredients that learners will use when thinking critically about and with NOS. As far as developing learners' NOS understandings is concerned, Abd-El-Khalick (2012a) has identified at least seven contexts that science education researchers have relied upon in designing explicit-reflective NOS interventions. These areas are (1) historical case studies, (2) authentic scientific practice, (3) inquiry-based contexts, (4) teacher professional development, (5) learning-as-conceptual change, (6) argumentation, and (7) meta-cognitive strategies. In terms of socioscientific decision making, Zeidler and Nichols (2009) consider the Internet and issues-based learning activities as resources to create contexts for exposing learners to diverse perspectives on current scientific reports and claims. Taking into consideration the fact that CT-NOS addresses the development of students' critical thinking both about NOS and with NOS, the background context needs to incorporate simultaneously elements that help learners to develop their NOS understandings as well as to engage in socioscientific decision making.

Critical thinking-related knowledge, skills and dispositions. If students are to practice making decisions about what views of NOS to adopt and decisions on socioscientific issues, then they need to learn *how* they can engage in such decision making. Such a position does not tend to limit the learning process to technical, applied, or *how-to* type of procedures. The *how* in this context is related to exposing students to critical thinking itself. As discussed in Chapter 2, critical thinking is used by those involved in philosophical discourse on NOS in debating and producing substantive NOS content. Hence, as I proposed earlier, bringing critical thinking into the foreground of school NOS favors a more authentic image of the substantive NOS content and the process of its development. Consequently, critical thinking is the particular type of inquiry that learners will engage in as they learn how to make decisions on their NOS views as well as on socioscientific issues.

As discussed in Chapter 3, a number of philosophers of education have attempted to define and characterize critical thinking. In the paragraphs that follow I continue from where I ended and engage in evaluations of Siegel's, Lipman's and Ennis's theories of critical thinking with the purpose of justifying my choice of Ennis's theory for the CT-NOS framework.

Harvey Siegel focuses on critical thinking in its broad sense. Siegel is mainly concerned with the overarching concept of critical thinking. He is not concerned with identifying what this overarching concept encompasses in detail. The greatest amount of detail to be found in Siegel's work lies in his arguments establishing connections between reasons, principles and consistency and in his analysis of the *reason assessment* and *critical attitude* components of critical thinking (Siegel, 1988). From a purely pedagogical standpoint, the lack of detail does not help to develop materials and resources that could be used by teachers and students. A more detailed conceptualization of critical thinking would be more useful as far as the CT-NOS framework is concerned.

Matthew Lipman's conceptualization of critical thinking contains more detail than Siegel's. Lipman (1988, 2003) highlights the importance of criteria in critical thinking and identifies a list of the kinds of criteria:

- Standards
- Laws, bylaws, rules, regulations, charters, canons, ordinances, guidelines, directions
- Precepts, requirements, specifications, gauges, stipulations, boundaries, limits, conditions, parameters
- Conventions, norms, regularities, uniformities, covering generalizations
- Principles, assumptions, presuppositions, definitions
- Ideals, purposes, goals, aims, objectives, intuitions, insights
- Tests, credentials, factual evidence, experimental findings, observations
- Methods, procedures, policies, measures. (Lipman, 2003, p. 213)

Lipman argues that in order to select among criteria one needs to rely upon other criteria, which he calls "metacriteria" (2003, p. 215). He considers *reliability*, *strength*, *relevance*, *coherence*, *precision*, and *consistency* as metacriteria. Lipman further argues for the existence of criteria of very high generality that are often presupposed whenever critical thinking takes place. He calls these "megacriteria" (p. 215) and considers *truth*, *right*, *wrong, just*, *good*, and *beautiful* as examples.

As students are taught to think critically, Lipman suggests teaching them to recognize and use these criteria, and to use them in a way that is both sensitive to context and self-corrective. Nonetheless, Lipman does not describe what each of these criteria would encompass at the detailed level. There is an implicit assumption that the critical thinker would have to know what is meant by *laws*, *observations* and *methods*, to name just a few from his list. Moreover, critical thinking skills are absent in his work; even though Lipman acknowledges that critical thinking is skillful thinking, he mentions these skills without illustrating them or delineating their characteristics:

> Critical thinking . . . is skillful thinking, and skills are proficient performances that satisfy relevant criteria. Without these skills, we would be unable to draw meaning from a written text or from a conversation, nor could we impart meaning to a conversation or to what we write. (Lipman, 2003, p. 227)

Unlike Siegel's and Lipman's work, Robert Ennis's work involves the dissection of critical thinking into concepts (Appendix A) and the description of these concepts with the aim of delineating critical thinking. These concepts form the knowledge base of the skills and some of the sub-skills that he considers essential in critical thinking. Siegel (1988) considers Ennis's work on critical thinking to be "crucially important, pioneering, and basic to inquiry in the field" (1988, p. 10). He regards Ennis's list of proficiencies as "the most detailed, complex, and useful to be developed" (1988, p. 10). From a pedagogical perspective, Ennis's list of concepts and criteria for those concepts are appealing because they provide a practical starting place for constructing a NOS curriculum. Ennis has devoted many years preparing and refining his critical thinking theory. Not only is his work a classic inside philosophy of education, but it is also widely cited outside the field of educational philosophy. Ennis's critical thinking theory has been studied in the context of curriculum and instruction as well as in educational assessment. In the paragraphs that follow I provide justifications for the use of Ennis's theory of critical thinking in the CT-NOS framework. I argue that the concepts and sub-concepts in Ennis's critical thinking theory (1) foster a framework for the development of educational programs, standards and resources; (2) facilitate in-depth discussions about NOS and with NOS; and (3) foster the development of learning progressions for NOS in school science.

Fostering a framework for educational programs, standards and resources. Ennis's concepts (and sub-concepts) of critical thinking, with their clearly defined sets of operational characteristics, provide not only clear goals and objectives for student learning but also a framework for educational programs and standards. The NSES document (NRC, 1996) illustrates program standards for the quality of school science programs. We read in this document: "In an effective science program, a set of clear goals and expectations for students must be used to guide the design, implementation, and assessment of all elements of the science program" (NRC, 1996, p. 210). Similarly, NRC (2012) recommends that standards be clear, concise and comprehensible to science educators.

Facilitating in-depth discussions about NOS and with NOS. Ennis's (1996a) concepts (and sub-concepts) of critical thinking, together with the criteria under these concepts, could comprehensively address the teaching and learning of critical thinking-related knowledge. They could also be easily situated within different background contexts reflecting various NOS themes (and socioscientific issues), thus facilitating the teaching and learning of the substantive NOS content. In fact, certain critical thinking concepts raised by Ennis are already NOS concepts themselves.

Ennis's analysis of critical thinking into concepts and sub-concepts creates a comprehensive frame of reference for both the teacher and the learner and acts as a mediator for one to penetrate more deeply into one's thinking. Learners can thus engage in deeper thinking about NOS and with NOS when guided to reflect on some of these concepts and sub-concepts. For instance, in developing understandings *about* observations, rather than being guided to reflect on observation at a surface level, learners can be led to reflect at more depth on Ennis's sub-concepts under *observing* (e.g., observation conditions, use of appropriate technology) and the sub-concepts under *reporting observations* (e.g., avoiding hearsay and producing records). Learners can also be guided to make critical judgments about reports of observations using their understandings of Ennis's sub-concepts for *assessing observation statements* (e.g., minimal concluding involved, credibility of the source) (Norris, 1984). Ennis has further dissected some of these sub-concepts into additional sub-concepts which makes learning even deeper. For instance, the *credibility of sources* is subdivided into eight sub-concepts (e.g., the lack of conflict of interest and the ability to give reasons). At a later stage a learner could be guided to *apply* her understanding of the concept of observation and its sub-concepts in order to engage in evaluating knowledge claims that involve reports of observations.

Fostering the development of learning progressions for NOS in school science. The diverse range of knowledge, skills and dispositions that are presented in Ennis's theory of critical thinking allows for the development of learning progressions with critical thinking as a progression unit. In particular, Ennis's concepts of critical thinking as ultimate learning outcomes can be placed at the end of developmental trajectories. Next, potential developmental pathways that learners follow in developing more sophisticated understandings of the critical thinking concepts over time can be explored. Some of the sub-concepts of critical thinking and the skills that Ennis highlights can be helpful as one creates such learning pathways, especially if they are also supported by empirical research on how children learn. This is discussed in more depth in Chapter 6.

In sum, then, after engaging in critical evaluations of Siegel's, Lipman's and Ennis's theories of critical thinking, this section has identified Ennis's theory as the most detailed, comprehensive and clear in terms of presenting concepts (and sub-concepts) of critical thinking. I have argued that these are essential features from a pedagogical standpoint because they facilitate moving into the details of curricula as well as producing educational programs and resources. Ennis's theory was also shown to have the potential for fostering NOS learning as a developmental progression as well as targeting in-depth discussions about NOS and with NOS.

In the paragraphs that follow I briefly describe the two additional components of the CT-NOS framework: critical thinking about NOS and critical thinking with NOS. As mentioned earlier these components are both processes and outcomes in the CT-NOS framework (Figure 1). In the last section of this chapter I construct two examples through which I further illustrate the CT-NOS framework.

Critical thinking about NOS. In this phase the ultimate goal is for students to think critically about NOS and to develop some NOS understandings (NOS as an educational end). One or a combination of dispositions, skills and their underlying concepts (and sub-concepts) proposed by Ennis could be targeted in this phase, depending on what learning activities the students are to engage. After students are engaged in the activities, they are invited to think critically about a chosen NOS theme. The expectation is that as a result they will develop (1) critical thinking skills, dispositions, as well as knowledge of these skills and dispositions; and (2) relevant understandings of the NOS theme in question.

Critical thinking with NOS. In this phase, the ultimate goal is for students to think critically with the NOS understandings that they have developed and to make decisions on the socioscientific issue in question. One or a combination of skills and their underlying concepts (and sub-concepts) proposed by Ennis could be targeted in this phase, as students are guided to make decisions about the socioscientific issue. As a result they develop (1) critical thinking skills, dispositions and knowledge of these skills and dispositions; (2) the ability to use their NOS understandings in making decisions about the socioscientific issue; and (3) knowledge of the socioscientific issue itself.

Illustration of the CT-NOS Framework through Two Examples

In this section I construct two scenarios to serve as examples for the applicability of the CT-NOS framework. In Chapter 6, I use the first example to build a concrete lesson plan that could be used with high school students.

In the present scenarios, students in a high school science classroom are asked to make decisions on socioscientific issues:

Q_a: Should cell phone usage be regulated by law?

Q_b: Should creationism be taught in my science class?

Both questions Q_a and Q_b could be targeted from a NOS perspective, as well as from political, policy, aesthetics, ethical, health and other perspectives. A good educator should guide the learners to engage in socioscientific decision making from multiple perspectives, given that various perspectives could be valuable and one may eventually make use of a combination of them in making judgments. Nonetheless, I delimit my discussion to the NOS perspective in this dissertation. I also believe that a good educator cannot guide her students to develop in-depth understandings of all the perspectives simultaneously. There is always choice involved in terms of which perspective will be the focus of discussion at a specific time, despite the fact that there could be room for integration among different perspectives.

As a first step, we need to provide a background context for each of Q_a and Q_b to focus the discussions. Let us assume that we decide to focus the discussion of Q_a on the relationship between long-term cell phone usage and the risk of brain tumor development. Let us also assume that we choose to focus the discussion of Q_b on the context of creationism and the tentative aspect of science. The purpose of the context is to establish a platform so that discussions about NOS and with NOS revolve around a concrete situation.

In order to appreciate the complexity of the issues, the learner needs to be exposed to the different viewpoints concerned. For instance, the learner could be guided to read contradictory scientific research reports on the relationship between long-term cell phone usage and the risk of brain tumor as she thinks about $Q_{a,}$ and she may read contradictory philosophical papers on creationism and the tentative aspect of science as she thinks about Q_b.

I acknowledge that high school students often are not in a position of being able to read primary literature in science and philosophy. Exposing students to adapted versions of these respective literatures might be a way of introducing the controversies. I will say more about adapting primary literature in Chapter 6. It is worth noting that the background context could also be presented through various other ways such as asking students to do some research by themselves.

As the learners are engaged in exploring Q_a and Q_b, they could be guided to focus on the following NOS-related questions:

Q_{a2}: To what extent does evidence suggest a relation between long term cell phone usage and risk of brain tumor?

Q_{b2}: To what extent are creationists' views on the origin of life tentative?

A learner needs to use her understandings of NOS in order to engage in a meaningful discussion and answer Q_{a2} and Q_{b2}. In particular, she needs to use her understandings of the terms "relation" and "tentativeness". In these situations the learner is being asked to engage in decision making *with* NOS. In other words she is being asked to *use* her NOS understandings to make judgments. Once she formulates her answers to Q_{a2} and $Q_{b2,}$ she is able to use those answers to answer Q_a and Q_b respectively.

Nevertheless, in order to be able to formulate her positions on Q_{a2} and $Q_{b2,}$ and in order to formulate them well, the learner needs to be provided with opportunities to analyze and evaluate what the terms "relation" and "tentativeness" mean in these contexts and what significance they have. These are key terms around which a philosophical discussion *about* NOS can happen. Consequently, in order for the learner to be able to answer Q_{a2} and Q_{b2} and answer them well, she needs to think in the first place about more fundamental questions. These questions could be as follows:

Q_{a1}: In what circumstances could a causal inference between variables be considered a strong one?

Q_{b1}: How is science tentative?

Note that in Q_{a1} the focus is being placed on developing understandings of causal inference, whereas in Q_{b1} the focus is on developing understandings of tentativeness in science. Accordingly, Q_{a1} and Q_{b1} emphasize NOS as an educational *end* where the learners are encouraged to make judgment *about* NOS.

In sum, when the learners have developed understandings of causal inference and tentativeness (Q_{a1} and Q_{b1} respectively), they can use these understandings to make judgments about Q_{a2} and Q_{b2} which will help them in making decisions regarding Q_a and Q_b respectively.

Situating Q_{a1} and Q_{a2} in the context of Ennis's critical thinking theory. Research studies that explore a relationship between long-term cell phone usage and the risk of brain tumor development are usually epidemiological in nature, and many of them are designed as case-control studies. Experimental studies on humans are rare. Q_{a1} is formulated so that learners can be guided to develop understandings of causal generalizations. Ennis (1996a) defines causal generalizations in terms of an unlimited number of possible sequences of one particular type of thing causing another particular type of thing. Ennis provides a list of elaborated criteria that one may use in evaluating causal generalizations. These criteria could be helpful in making judgments related to Q_{a1}. Ennis says that support for a causal generalization is based on its ability to satisfy seven criteria. These seven criteria are found in Appendix D.

These criteria could constitute a knowledge base for learning about causal generalizations; nevertheless, knowing these criteria does not mean that the learners will be able to apply them effectively in any situation and make good judgments. Learners need to be trained to apply them in different situations, and to apply them effectively. Ennis himself acknowledges that the above mentioned criteria are "loose criteria" (1996, p. 252) and that "good judgment, background knowledge of the facts that serve as reasons (R) and counterreasons, and sensitivity to the situation (S) are required in applying the criteria" (1996, p. 252). Applying these criteria is a skill that needs to be mastered over years. As stated repeatedly in this dissertation, there is a need to engage students in situations where they can *practice* making decisions on their NOS understandings and *practice* using their NOS understandings to make judgments on socioscientific issues. Indeed Ennis's (1996a) FRISCO approach, described previously, provides a good framework as the learner practices those skills.

Once the learners have given some thought to causal generalizations, they are in a better position to think about Q_{a2}. Here they are guided to use their understandings of causal relationships to evaluate the extent to which evidence supports a relationship between long-term cell phone usage and the risk of brain tumor. This might require the learner to analyze studies involving long-term cell phone usage and risk of brain tumor with the purpose of developing an understanding of the context, and then to apply her understanding of causal generalizations to this new context. Finally, the learner can be guided to defend a position regarding Q_a. The FRISCO approach may be helpful here too, as the learner develops a position on what to believe or what to do.

Situating Q_{b1} and Q_{b2} in the context of Ennis's critical thinking theory. Philosophers of science offer different interpretations of tentativeness in science. Consequently, Q_{b1} is designed so that students can engage in critical analysis of some of these interpretations and try to make judgments on them. Ennis's criteria of accepting best explanations (1996a, p. 219) might be helpful here. These are (1) *the ability to explain some of the facts,* (2) *alternative* *explanations being inconsistent with some fact or facts*, (3) *being itself consistent with the facts*, and (4) *being plausible*.

Again, knowing these criteria is not the end of the story. This knowledge does not make the learners capable of applying them effectively and skillfully in any situation in order to make good judgments. As argued earlier, learners need to be guided in applying them effectively in different situations.

Once the learners have given some thought about tentativeness in science, they are in a better position to explore Q_{b2} and to engage in critical thinking with NOS. At this stage, the learners can be guided to apply their understandings of tentativeness in science to evaluate the extent to which creationists' views on the origin of life could be subject to change. This might require the learner to analyze accounts of tentativeness in the context of the issue in question with the purpose of developing an understanding of the context, and then to apply her understanding of tentativeness to this context. Finally, the learner can be guided to defend a position regarding Q_b. The FRISCO approach could be helpful here as well.

At this stage the reader might be wondering about the type of guidance and resources that need to be provided to learners, the type of activities that learners would need to engage in as they attempt to think about these questions, and details of the lesson stages. Answers to these questions are found in Chapter 6 and Appendices A to E and I. First, however, I need to explore some developmental aspects of the CT-NOS framework; this will be the topic of the next chapter.

Chapter 5

A Developmental Context for the CT-NOS Framework

In this chapter I situate the CT-NOS framework in a developmental context. Particularly, I borrow from the literature on learning progressions in science education in order to examine how the CT-NOS framework could help to situate NOS learning across a developmental trajectory. After reviewing relevant literature on learning progressions, I discuss how the CT-NOS framework can be sensitive to developmental needs of learners, arguing for developing learning progressions related to critical thinking rather than to the substantive content of NOS. Next, I critically evaluate King and Kitchener's (1994) developmental model of reflective judgment and Kuhn's (1999) developmental model of critical thinking. I evaluate the extent to which these models could be used for building developmental progressions for critical thinking. Finally, I explore the likelihood of developing learning progressions for NOS learning using Ennis's critical thinking theory, and offer an example.

Learning Progressions in Science Education

The notion of learning progressions has received some attention in recent years in the science education literature as a means of moving the focus from curricular coverage of disconnected science concepts to considering how students' understanding of a concept can be supported as they move from grade to grade. Learning progressions, according to Duschl et al. (2007), can be viewed as proposals of intermediate understandings between (a) the concepts and reasoning of students entering school (supported by developmental literature) and (b) societal expectations and research-based conceptual and social analyses of the disciplinary knowledge and practice to be learned.

Corcoran, Mosher, and Rogat (2009) claim that learning progressions are testable hypotheses that are based on research into how students' learning actually progresses, rather than on selecting topics and learning experiences that are based on logical analysis of current disciplinary knowledge and personal teaching experiences. These hypotheses can later be tested for determining their construct as well as consequential validities.

Duschl et al. (2007) identify key characteristics of learning progressions. They highlight the importance of grounding the work in current research on children's learning; organizing learning progressions around core ideas, conceptual frameworks and models that have broad explanatory power; and recognizing the possibility of multiple sequences or paths that students might pass through while developing more sophisticated understandings.

Corcoran et al. (2009) and Duschl et al. (2007) consider several benefits of learning progressions. These benefits are (a) improving curriculum and standards, (b) determining age appropriateness for introducing key ideas, (c) determining large-scale and classroom assessment tools and strategies, and (d) guiding classroom instruction. Smith, Wiser, Anderson, and Krajcik (2006) take a similar stance. They highlight the importance of using research on learning to elaborate science education standards in curriculum documents, as well as to design and interpret standard-based assessments. They consider learning progressions as a means for organizing standards around big ideas, connecting standards to empirical evidence about children's learning, and establishing connections between conceptual knowledge in the standards and the practices (i.e., the coordination between knowledge and skills). As far as assessment is concerned, Smith et al. (2006) suggest that big ideas and practices could be codified into learning performances which could be used to develop clusters of assessment tasks. The research could be used as a basis for the interpretation of students' responses.

Smith, Wiser, Anderson, Krajcik, and Coppola (2004) set forth four main caveats regarding learning progressions. They agree that there is no single pathway that can describe a learning progression of a particular topic and that actual learning is more sophisticated than proposals from research in learning progressions because of changes happening in multiple interconnected ways. Moreover, learning progressions are hypothetical in nature because no longitudinal studies support the accounts of student learning. Finally, the authors acknowledge that describing students' reasoning could be problematic because the available research uses various conceptual frameworks and methods.

Catley, Lehrer, and Reiser (2005) trace a learning progression for developing an understanding of evolution. These researchers identify foundational concepts or big ideas in the field of evolution. The big ideas are, according to the researchers, "generative, in that reasoning about them typically spawns rich sets of questions, investigations, and models of evolutionary products and processes" (p. 6). In addition to these concepts, the researchers also treat mathematical tools, systems of notation, and forms of argument as big ideas, as these are often necessary in developing an understanding of evolution. Next, the researchers describe research that highlights student learning about the big ideas that they have identified. Finally, they chart the development of the big ideas and associated learning performances across primary, elementary and middle grades. They argue that the research evidence about student learning is incomplete and sometimes contradictory, highlighting the importance of treating their proposed learning performances as “signposts for the nature of research that would be needed to construct a more compelling account of prospective development” (p. 7).

Smith et al. (2004) trace a learning progression for coming to understand atomic molecular theory. These researchers argue that children’s understanding of atomic theory requires related understandings about nature of matter and material kinds, how matter and materials change, and the atomic structure of matter. The researchers organize these understandings into six big ideas, of which some are at the macroscopic level (e.g., macroscopic conversion) while others are at the atomic-molecular level (e.g., the atomic-molecular explanation of transformations). Next, the researchers review the research on student learning with the purpose of setting forth a learning progression. Finally, they justify learning performances and assessment tasks in the grade ranges of K-2, 3-5 and 6-8.

Learning Progressions in the Context of the CT-NOS Framework

I illustrated the main features of the CT-NOS framework in Chapter 4. As critical thinking *about* NOS and critical thinking *with* NOS are two main processes and outcomes in this framework, one might wonder about the developmental journey that school students pass through as they learn to engage in critical thinking about NOS and with NOS. This section highlights how research on learning progressions can be used to place the CT-NOS framework in a developmental context in order to be sensitive to the developmental needs of learners.

Several components of the CT-NOS framework need to be sensitive to learners' needs, backgrounds and potentials. For instance, the *background context* needs to include material that is appropriate to the age level of the learners and relevant to their everyday experiences. To use one of the examples raised previously – a learner evaluating whether *creationism* is science – the background context would then include material that sheds light on the theme of creationism. It might be too advanced to have such a background context as the basis to engage elementary students in NOS discussions. The lesson might not be meaningful to them, not only because they may lack the prerequisite knowledge and background required to engage in discussions on the chosen topic, but also because the theme itself might be irrelevant to them. Such a discussion might be more suitable at the middle and secondary levels.

However, when I refer to *developmental needs* of learners, I have in mind something more than curricular coverage of the substantive content of NOS. What

I am trying to address is the developmental journey that learners pass through and how they become more proficient over time in handling a discussion that reflects a certain NOS theme and a socioscientific issue. In other words, I am interested in how the earlier years of life prepare learners to engage in such discussions, how their thinking progresses with time, and what paths they need to follow so that they can eventually engage in successful critical discussions about NOS and with NOS. Such a developmental conceptualization highlights the importance of creating a developmental pathway for NOS learning, and *learning progressions* literature may be helpful in that regard.

One might think about a developmental pathway for NOS learning in terms of a learner's handling of the substantive content of NOS – or, in other words, how the substantive content of NOS needs to be adapted to the developmental needs of learners at different levels. How, for instance, does the idea of tentativeness of science need to be adapted so that it is meaningful for an elementary student, and how should it be adapted to be meaningful for a secondary student? One might also think about a developmental pathway for NOS learning in terms of a learner's engaging in critical thinking about NOS and with NOS. How does the thinking process itself need to be adapted to the developmental needs of learners at different levels? It is the latter that I intend to address in this chapter, while acknowledging the importance of the former. I discuss the reason in the paragraphs that follow.

Learning progressions in science are built based on core concepts (Duschl et al., 2007; Smith et al., 2006), about which there is some consensus among scientists and science educators. For example, there is little disagreement among scientists and science educators that evolution (Catley et al., 2005) and the atomic-molecular explanation of transformations (Smith et al., 2004) are core concepts. Moreover, there is some agreement on what could be considered a shallow versus a sophisticated understanding of the substantive content of science, at least as far as the substantive content of school science is concerned. At the level of school science curriculum, there is fair agreement among scientists and science educators regarding the attributes of a sophisticated understanding of evolution or of the atomic-molecular explanation of transformations.

However, the substantive content of NOS and the substantive content of science are quite different in their natures. Unlike the substantive content of science, there is less agreement among philosophers, sociologists, historians of science and science educators about the substantive content of NOS. As competing viewpoints on NOS often form the substantive content of NOS, there is not likely to be perfect agreement, for example, as to what might be considered shallow versus sophisticated ideas of NOS. Consequently, in developing learning progressions for NOS, it may be quite hard to determine the *societal expectations*, to use Duschl et al.'s (2007) words. In other words, it may be a challenge to define and determine sophisticated understandings of NOS in order to place them at the end of a learning progression. The science education literature reviewed in Chapter 2 shows that it has already been a challenge to determine whose NOS to address in school science. What do we expect learners to have mastered in terms of the substantive content of NOS upon completion of secondary school? For example, should a realist or a constructivist position regarding tentativeness in science be considered a sophisticated NOS idea that could be placed at the end of the learning progression?

Nonetheless, Duschl et al. (2007) do not limit the endpoints of learning progressions to substantive content. These researchers highlight the importance of *practices* as important outcomes that could be placed at the end of learning progressions. Catley et al. (2005), for instance, include mathematical tools, systems of notation, and forms of argument as big ideas as they develop a learning progression for evolution. One practice of the field that I have highlighted in the present work is *critical thinking*. I have shown that critical thinking is a major mechanism used by those involved in philosophical discourse on NOS to produce the substantive content of NOS. I have also argued for the adoption of critical thinking as a foundational pillar of NOS in school science and have proposed moving NOS as a set of concepts/ideas from the foreground of NOS instruction into the background.

Accordingly, it would be more plausible to think about developing learning progressions for the meta-content of NOS – in other words, for critical thinking itself. Ennis's concepts and sub-concepts of critical thinking could be used in developing learning progressions. I discuss how later in this chapter. When the concepts of critical thinking are placed across a developmental trajectory, both critical thinking about NOS and critical thinking with NOS acquire a developmental nature. An underlying assumption for such a proposal is that at least some concepts that define critical thinking might enjoy a wider consensus among scientists, science educators and philosophers of science than does the substantive content of NOS. With the latter being in the background of NOS in school science, we could then think about developing discussions on themes that are appropriate to the age level of the learner and relevant to her experiences. We need not enter into debates regarding whose NOS to constitute the endpoint of learning progressions.

In the present section I highlighted the importance of having critical thinking as the main target in developing a learning progression for NOS in school science. The rest of the chapter will deal with critical thinking itself. It is beyond the goal of this chapter to propose NOS themes and adapt them to appropriate age levels and experiences. In Chapter 6, I present one NOS theme and show how to adapt it to the secondary level. However, the purpose of adapting the NOS theme, as mentioned earlier, is to provide a background context that is appropriate to the age and interests of the student, and as such the adaptation of the substantive content of NOS does not directly contribute to the learning progression itself. In the next section I critically evaluate two developmental models – the first on reflective judgment, developed by King and Kitchener (1994), and the second on critical thinking, developed by Kuhn (1999). I evaluate the extent to which these models could be used towards building learning progressions for critical thinking.

Developmental Models of Reflective Judgment and Critical Thinking: A Critical Evaluation

In this section I engage in critical evaluation of King and Kitchener's (1994) developmental model of reflective judgment and Kuhn's (1999) developmental model of critical thinking. I argue that while the models are valuable resources for use in understanding how people's reflective judgment and critical thinking become more sophisticated over time, they provide a number of challenges when one tries to use them to create a developmental trajectory for NOS in school science with critical thinking as a progression unit. I explore the potential of Ennis's critical thinking theory in meeting these challenges.

Based on developmental psychology research and as a result of their investigations into how adolescents and adults make judgments on ill-defined controversial problems, King and Kitchener (1994) have argued that there is a developmental sequence in the patterns of judgments on these problems, and have therefore developed the Reflective Judgment Model (RJM). The model consists of seven stages that reflect increasing levels of complexity and abstraction regarding the nature of knowledge and reality, as well as the justification of beliefs.

King and Kitchener's model provides a description of the developmental pathway for the view of knowledge and concept of justification. The researchers describe how people's justification patterns become more sophisticated over time in parallel with their views of knowledge. In their overview of the model, King and Kitchener (2004) divide the seven stages of the model into three groups. Stages 1-3 are classified as pre-reflective thinking. During these stages knowledge is assumed to be certain and single correct answers to every problem are assumed to exist. Moreover, pre-reflective thinkers do not use evidence to support a conclusion. Stages 4-5 are classified as quasi-reflective thinking. During these stages uncertainty is considered to be part of the knowing process; knowledge is viewed as an abstraction and recognized as being constructed. Quasi-reflective thinkers highlight the role of evidence in shaping several perspectives on controversial issues. Stages 6-7 are classified as reflective thinking. Reflective thinkers consistently use evidence and reason to support their judgments. They highlight the role of context in understanding knowledge claims and the role of reevaluating one's conclusions and knowledge claims in light of new perspectives.

King and Kitchener's model highlights macro-level features of the concept of justification. It describes how one's concept of justification becomes more sophisticated over time, yet it does not delineate what it may mean at the micro-level. Here is an example. Let us consider two consecutive stages in King and Kitchener's model (Stages 3 and 4) regarding the development of the concept of justification. The researchers claim:

> [Stage 3] *Concept of justification*: In areas in which certain answers exist, beliefs are justified by reference to authorities' views. In areas in which answers do not exist, beliefs are defended as personal opinion since the link between evidence and beliefs is unclear. (King & Kitchener, 1994, p. 14)

> [Stage 4] *Concept of justification*: Beliefs are justified by giving reasons and using evidence, but the arguments and choice of evidence are idiosyncratic (for example, choosing evidence that fits an established belief. (King & Kitchener, 1994, p. 15)

In the progression between King and Kitchener's third and fourth stages, one moves from justifying beliefs based on personal opinion and having an unclear link between evidence and beliefs (in Stage 3) to justifying beliefs based on reasons and evidence (in Stage 4). It is clear that one's concept of justification becomes more sophisticated as one moves from Stage 3 to Stage 4, yet such a description of the transition is only at the macro-level and does not provide what it may mean at the micro-level. It is not clear *how* a person moves to establish a link between evidence and beliefs and *what* makes a person start giving reasons to justify beliefs and use evidence. Such descriptions at the micro-level are necessary to fill in the gaps and make the overall picture more clear, precise and complete.

To describe developmental change at the micro-level, one needs to rely on a framework that delineates micro-level features of critical thinking. Ennis's critical thinking theory has the potential of meeting this challenge because it analyzes critical thinking into micro-level concepts and sub-concepts. Accordingly, it would be helpful, for instance, to use Ennis's theory in order to identify what sub-concepts constitute the concept of *causal inference* (Ennis, 1996a). Upon having the sub-concepts of causal inference as a starting point, a researcher can focus on them to better understand *how* change happens as the learner moves from Stage 3 to Stage 4 on King's and Kitchener's model, *what exactly* develops when one moves from personal opinions into providing reasons and evidence in defending justifications, and *what* makes one give reasons and use evidence to justify one's beliefs. Consequently, Ennis's micro-level concepts might help us to better understand how one progresses in one's reflective judgment and how one thinks in more sophisticated ways as one moves through these stages.

Let us turn now to Kuhn's developmental model of critical thinking. Based on empirical research on cognitive development, Kuhn (1999) argues that the process of developing cognitive competencies in critical thinking is metacognitive in nature. Metacognitive skills, unlike first-order cognitive skills, are second-order or meta-knowing skills that help one to know about one's own and others' knowing. The empirical evidence upon which Kuhn bases her proposal is derived from microgenetic studies that she and others have performed with young children and adults regarding strategies that they use in coordinating understandings with new evidence.

Kuhn differentiates between three forms of metaknowing: those which are metastrategic, metacognitive and epistemological. She provides evidence for the developmental origins of each and argues that all three forms of metaknowing are central to critical thinking. She argues that the development of metacognitive understanding is important for critical thinking because the latter, by definition, involves reflection on what is known and how that knowledge is justified. Metastrategic skills, on the other hand, are important to critical thinking because their possession by thinkers enable them to apply consistent standards of evaluation across times and situations. Finally, the development of epistemological understanding is considered by Kuhn to be most fundamental to critical thinking, as people must understand the point of thinking if they are to engage in it.

Kuhn provides four levels of epistemological understanding and argues that her developmental framework conceptualizes students' potential to engage in critical thinking. In the first or *realist* level, assertions are treated as copies representing an external reality; knowledge is considered to be certain and critical thinking to be unnecessary. Assertions in the second or *absolutist* level are treated as facts that could be correct or incorrect. Knowledge is considered to be certain, while critical thinking is regarded as a vehicle to compare assertions to reality. Assertions in the third or the *multiplist* level are treated as opinions accountable only to their owners; knowledge is uncertain and critical thinking is irrelevant. Finally, in the fourth or the *evaluative* level, assertions are treated as judgments that may be evaluated and compared according to criteria of argument and evidence. Knowledge is uncertain, while critical thinking is a vehicle that produces sound assertions.

Unlike Ennis, who focuses on the cognitive aspects of critical thinking, Kuhn's focus is on the metacognitive aspects. She writes:

> A second distinctive feature of the present effort is that the developing cognitive competencies I describe as most relevant to critical thinking are metacognitive – rather than cognitive – competencies. In contrast to first

> order cognitive skills that enable one to know about the world, metacognitive skills are second-order *meta-knowing* skills that entail knowing about one's own (and others') knowing. (Kuhn, 1999, p. 17)

The developmental focus on the metacognitive competencies of critical thinking is on how views *about* critical thinking become more sophisticated. This is different from the question of how critical thinking itself can become more sophisticated. Indeed, as one moves up through Kuhn's levels, one exhibits more sophisticated views *about the role of critical thinking* in one's own and others' knowing. For example, on the absolutist level, critical thinking is viewed as a vehicle to compare assertions to reality while on the evaluative level critical thinking is regarded as a vehicle that produces sound judgments.

Kuhn focuses on "skills" of critical thinking as first-order or cognitive level knowledge. In her view, practicing critical thinking skills is important, but it needs to be complemented with metacognitive understanding. She writes:

> Regular practice of the skills we would like to see develop is essential, we know, but practice does not make perfect in the absence of understanding. The best approach, then, may be to work from both ends at once – from a bottom-up anchoring in regular practice of what is being preached so that skills are exercised, strengthened, and consolidated as well as from a top-down fostering of understanding and intellectual values that play a major role in whether these skills will be used. The developmental goal is to put people in metacognitive and metastrategic control of their own knowing. (Kuhn, 1999, p. 24)

There are two problems that arise here. First, critical thinking competencies at the first-order or cognitive level cannot be limited to *skills* of critical thinking. There is a body of knowledge that underlies many of these skills (Ennis, 1996a; Gott, Duggan, Roberts, & Hussain, 2002; NRC, 2012), and it is important that one develops understandings of them in addition to mastering the skills. As shown in the above quote, Kuhn's primary focus on the cognitive level is on the mastery of these skills rather than on building a knowledge base for these skills.

Second, despite the high significance of the developmental nature of the second-order metacognitive competencies, it is important to treat the first-order cognitive competencies as developmental as well. When the developmental progression is targeted to the first-order or the cognitive level, it will be necessary to place the relevant knowledge and abilities that define critical thinking across a developmental trajectory. When a developmental trajectory for the first-order competencies becomes available, it can then be correlated with the developmental trajectory of the second-order or the metacognitive. Establishing a correlation will help us to better understand the extent to which both trajectories are compatible. Moreover, developmental trajectories for both the first-order and second-order competencies will better describe the developmental journey of critical thinking by making it more precise and complete.

Ennis's critical thinking theory has the potential of meeting these two challenges. Particularly, as discussed previously, the concepts and sub-concepts of critical thinking in Ennis's theory provide a knowledge base for the critical thinking skills. In addition, these concepts and sub-concepts of critical thinking can act as necessary building blocks for developing learning progressions. I discuss how in the next section.

In sum, I reviewed King and Kitchener's (1994) model of reflective judgment and Kuhn's (1999) model of critical thinking. King and Kitchener propose a developmental trajectory that captures the macro-level developmental changes over time as learners develop sophisticated understandings of the nature of knowledge and the concept of justification. I argued for the need to borrow from Ennis's theory because it delineates the micro-level characteristics of critical thinking. The concepts and sub-concepts of critical thinking in Ennis's work can provide a researcher with a frame of reference supporting a more precise understanding of the development described in King and Kitchener's model. Kuhn's model highlights the development of metacognitive competencies as being fundamental to the development of critical thinking. I argued that the cognitive competencies of critical thinking, in addition to the metacognitive ones, need to be viewed as developmental, and that the cognitive competencies need not be limited to skills but also to the knowledge base that defines those skills. I argued that Ennis's critical thinking theory is helpful in that regard as it provides a knowledge base for the critical thinking skills. Moreover, I proposed that the concepts and sub-concepts of critical thinking in Ennis's theory can act as necessary building blocks for developing learning progressions.

Towards Developing Learning Progressions Based on Ennis's Concepts and Sub-Concepts of Critical Thinking

In this section I borrow from the literature of learning progressions in science education to discuss the likelihood of developing learning progressions for NOS in school science using Ennis's concepts and sub-concepts of critical thinking.

Catley et al. (2005), Duschl et al. (2007), and Smith et al. (2004) recommend that learning progressions be organized around core concepts. Catley et al. and Smith et al. define lists of core concepts in evolution and atomic molecular theory respectively, and place those core concepts at the end of a continuum, arguing that school science needs to prepare students to eventually develop understandings of those core concepts. The core concepts identified by these researchers are not limited to substantive science content; they also include scientific practices. Ennis's concepts are core concepts in critical thinking, and school science needs to provide opportunities for students so that they can develop understandings of these core concepts. Like the approach utilized by the researchers mentioned above, Ennis's concepts of critical thinking can be placed at the end of learning pathways.

At the other end of the continuum, one needs to consider what children bring into school. Learning progressions, according to Duschl et al. (2007), need to be built upon students' pre-existing knowledge and reasoning, supported by developmental literature. There is some evidence that the roots of critical thinking can be traced back to the early years of life. A number of researchers (e.g., Duschl et al., 2007; Keating, 1988; Nicoll, 1996) argue that children can do quite a great deal with critical thinking, in spite of not necessarily being metacognitive about it (Kuhn, 1999). Duschl et al. argue against the view that young children are concrete and simplistic thinkers. In a critical review of the literature, they show evidence that young children's thinking is actually quite sophisticated and that the building blocks for such thinking are in place even before children start attending school. The researchers argue that children at the end of preschool can reason in ways that could provide helpful starting points for developing scientific reasoning. Similarly, Nicoll (1996) claims that the roots of critical thinking could be traced back to early in life, specifically when infants move into toddlerhood and start developing a sense of autonomy. Nicoll claims that 5- to 8-year-old children have developed autonomy, have a sense of wonder and curiosity, and show the ability to make choices. The researcher argues that young children at the primary level need to develop critical thinking skills and dispositions. They need to be trained to recognize different points of view and to display a willingness to explore alternatives. Undoubtedly, more research is needed in developmental psychology that identifies more precisely the precursors of critical thinking that are available when children start school so that one could have them as bases in tracing learning progressions for critical thinking and ultimately linking what students bring to school with the understandings that we want them to develop around core concepts.

Next comes the challenge of understanding how children develop more sophisticated understandings related to core concepts over time. In terms of critical thinking, there is a need to understand how children's critical thinking develops over time. Keating (1988) evaluates the validity of the claim that adolescents have fundamental limitations in their abilities to engage in critical thinking. The researcher reviews the evidence in four areas, namely Piaget's formal operations, biopsychological constraints, individual differences, and cognitive processing analyses. Keating concludes that "there is no evidence of fundamental constraints on the ability of early adolescents to engage in critical thinking" (p. 5). The researcher claims:

> (a) Performance is often the result of a person's experience, education and formal training in highly specific content areas; (b) brain growth and physiological maturation have not been isolated to substantiate clear connections to cognitive performance in early adolescence; and (c) neither research on individual differences nor on cognitive processing has established the influence of general underlying and untrainable capacities on cognitive performance in specific domains. (Keating, 1988, pp. 5-6)

Keating shows evidence that in specific areas, highly motivated children and adolescents demonstrate impressive cognitive performance, suggesting a great potential for critical thinking. Keating attributes the low critical thinking levels of adolescents to the structure of educational practices.

Catley et al. (2005) and Smith et al. (2004) identify developmental research that suggests how children develop understandings of the big ideas in evolution and atomic molecular theory respectively. The relevant research body forms the basis upon which the development of a learning progression is attained.

Eventually, based on relevant research literature, Catley et al. and Smith et al. propose a more detailed curriculum by delineating learning performances and assessment tasks. In a similar manner, a plausible path would involve consulting relevant developmental literature in critical thinking in order to understand how children develop understandings of Ennis's concepts of critical thinking and how their understandings of these concepts get more sophisticated over time.

Ennis's sub-concepts of critical thinking can be helpful in creating the necessary focus while consulting the literature, as they can guide our search for specific literature regarding the ways in which children develop more sophisticated understandings of the micro-level sub-concepts. An example is provided in the last section of this chapter. When such a path is taken, one is more likely to understand the developmental relationship between the sub-concepts and concepts of critical thinking. Whatever the relationship happens to be in each particular situation, the work will be plausible because it will help to delineate potential testable hypotheses beneficial for research in critical thinking. Such a proposal also fulfills Kuhn's (1999) suggestion of bringing research on critical thinking in developmental psychology and philosophy of education closer to each other.

The developmental literature reviewed suggests that the roots of critical thinking can be traced back early in life, that children and adolescents can do a great deal with critical thinking, that critical thinking is developmental, and that educational programs have a crucial role in shaping children's and adolescents' critical thinking. Consequently, I argued for using Ennis's concepts and sub-concepts of critical thinking towards building learning progressions for critical thinking. It is beyond the scope of this dissertation to actually build learning progressions for all Ennis's concepts of critical thinking – that could be a research agenda by itself. The intention here was to place the CT-NOS framework in a developmental context, emphasizing the importance of having critical thinking as a progression unit rather than the substantive content of NOS. In the last section of this chapter I present an example of how one of Ennis's concepts of critical thinking and associated sub-concepts contribute towards a learning progression. The section serves as an example of building a learning progression and needs to be considered as work in progress.

Causal Generalizations: An Example

Ennis (1996a) considers causal inference as one core concept of critical thinking. He argues that in order for someone to be able to evaluate a causal inference, and in particular a causal generalization, she should be looking at seven criteria. These criteria are found in Appendix D.

Causal inference in general and causal generalization in particular is a core idea in critical thinking around which students need to develop sophisticated understandings. The concept is not easy to acquire, given that there are a number of practices that the learner needs to master, in terms of developing both skills and relevant understandings, so that she can develop a meaningful understanding of causal generalizations. Consequently, placing this concept at the end of a learning progression creates the need to understand the developmental journey that learners pass through so that they could eventually develop meaningful understandings of causal generalizations.

There are at least four themes that can be derived from the list of criteria for evaluating causal generalizations. These themes can be considered as sub-concepts under the concept of causal generalizations. These are (1) causality, (2) representativeness, (3) controlled experiments, and (4) credibility. These sub-concepts help to guide us in reviewing relevant developmental literature with the purpose of determining how students develop understandings around them over time. Moreover, if the list of seven criteria is to be introduced to secondary students, then it is imperative that the students hold the necessary prerequisites and be developmentally ready to handle the complexity of such a discussion. One hypothesis that could be set forth here is that some understanding of these four sub-concepts may place the student in a better position to understand Ennis's criteria for evaluating causal generalizations and engaging in meaningful critical discussion *about* and *with* causal generalizations.

But how do students develop meaningful understandings of these four sub-concepts? In the paragraphs that follow each of these sub-concepts is elaborated. I explore the ways in which children in early years develop their understandings of these four sub-concepts, supporting claims with relevant findings from the literature. It is worth remembering that the literature reviewed in this section is not exhaustive but a sampling in order to illustrate how Ennis's concepts and sub-concepts can be placed in a developmental context. I also acknowledge that developing a more accurate picture requires a combined effort between educators and psychologists. The literature reviewed shows the likelihood of developmental paths that children pass through while developing their understandings of these four sub-concepts.

Causality. A review of the literature shows that the roots of human causal perception can be traced back to the infant years. Several researchers (e.g., Cohen & Oakes, 1993; Leslie, 1984; Leslie & Keeble, 1987; Oakes & Cohen, 1990) have investigated infant causal perception. Infants seem to move their focus gradually from the physical changes involved in an event to the causality of an event.

Oakes and Cohen (1990) and Cohen and Oakes (1993) reported that 6-month-old infants responded to physical changes in an event rather than to causality, whereas 10-month-old infants did respond to causality of events. Cohen and Oakes (1993) conducted a series of experiments with 10-month-old infants and concluded that specific objects participating in an event are important in infants' perception of causality. The researchers also reported that the 10-month-old infants formed an association between specific objects serving as an agent and the type of action (whether direct launching or delayed launching), whereas a similar association was not formed between the type of action and the recipient. Therefore, the researchers argued that the type of agent rather than the recipient is more closely tied to infants' notion of causality.

The focus on the type of agent rather than the recipient seems to stay with children for a while and seems to be reflected in their causal language. Muentener and Lakusta (2011) investigated how early conceptual representations of causality may influence conceptual and linguistic representation of causality later in development. The researchers conducted three experiments with 3.5- to 4-year-old children. They presented causal events in which they manipulated both the type of agent (human acting intentionally or unintentionally, or inanimate object) and the type of effect (motion or state change). The researchers studied how the children mapped the events into language. Muentener and Lakusta found that the type of agent rather than the type of effect influenced the participants' causal language. Moreover, the children used, and preferred using, more causal language to describe events caused intentionally by humans than to describe events caused unintentionally or by an object. Consequently, the researchers argued that the children had "intention-to-cause bias" (p. 352). However, the children did not show evidence for bias in the non-linguistic representations of the events.

In a longitudinal study, Hickling and Wellman (2001) examined the causal explanations provided by four children, ages from 2.5 to 5 years old, by focusing on the content of explanations that the children gave in naturalistic settings. The children were native English speakers. The researchers found that at age 2-3, the children gave causal explanations more than once in every 25 utterances; moreover, the children's causal explanations increased in frequency with age. The children's explanatory statements and questions mainly involved varied entities (humans, animals, objects) and incorporated psychological, physical, social-conventional and biological reasoning.

Finally, children at age 8 seem to understand and use the causal properties of statements when attempting to comprehend a text, but in the adolescent years they become more successful in transferring causal properties of statements across contexts. Van den Broek (1989) investigated the development of the ability to judge the importance of story statements based on their causal properties – specifically, the number and kinds of causal relations. Seven hundred and fifty-seven students of age groups 8, 11, 14 and 18 participated in this study. The researcher reported that students in all age groups were able to judge a goal statement to be more important when it had many causal relations to other statements within the same episode than when it had fewer causal relations. The researcher concluded that children as young as 8 years of age can understand and utilize causal properties of statements as they attempt to comprehend a text. Nonetheless, the researcher reported developmental differences among the participants as far as the kinds of relations were concerned. The important judgments of younger students were less influenced by relations across episodes than were those of the older participants.

Based on the literature reviewed in this section, a developmental path of causality can be traced: infants gradually move from responding to physical changes in an event to responding to the causality of events. Specific objects and type of agent are initial foci in infants' notion of causality and remain so for some time over the early childhood years, influencing conceptual and linguistic representations of causality. Children gradually develop more causal explanations as well as the ability to understand and use causal properties of statements. Adolescents become more successful in transferring causal properties of statements across contexts.

Representativeness. The development of the roots of the notion of representativeness could be found in early childhood mathematics curricula. The mathematics education standards proposed by the National Council of Teachers of Mathematics in the United States (NCTM, 2000) highlight the importance of selecting and using appropriate statistical methods to analyze data. Pre-K to Grade 2 students are expected to "describe parts of the data and the set of data as a whole to determine what the data show" (p. 108). Similar trends have been present in curricular documents in Australia, England & Wales and New Zealand (Watson & Moritz, 2000b).

There is some evidence that children's notion of representativeness develops gradually and emerges quite early in the elementary years. Mokros and Russell (1995) explored fourth, sixth and eighth graders' concepts of average and representativeness. In particular, they investigated how children construct and interpret representativeness when they are asked to describe a real data set. The researchers interviewed 21 students in total using a series of open-ended problems that examined the notion of average. The students had all been taught to compute average as part of their mathematics class. After examining the data collected, the researchers were able to group the participants' approaches into (a) approaches that do not recognize the notion of representativeness (e.g., recognizing average as mode and average as an algorithmic procedure) and (b) approaches that do embody a notion of representativeness (e.g., considering average as what is reasonable, recognizing average as midpoint and average as a mathematical point of balance). The researchers argued that the students belonging to the first group, and especially those who recognize average as mode, were mostly the youngest in the group and were not yet treating a data set as an entity; hence *representativeness* did not have a meaning for them. Comparing these findings to their classroom work, the researchers concluded that by the fourth grade, students are just beginning to develop ideas about values that represent a data set as a whole. The researchers argued that “children construct the idea of representativeness through many encounters with a variety of real data sets” (p. 37). In an earlier paper (Russell & Mokros, 1990), the researchers claimed that children begin developing a sense of representativeness when they start thinking about the relation between data and typicality.

Makar and McPhee (2009) explored third grade students’ understandings of the notion of the average in an inquiry classroom. The students were supposed to make sense of the question: Is there a typical height for a student in Year 3? The researchers found that the students’ ideas about average developed over time. Initially the students showed an understanding of typical as meaning *reasonable*; progressively they moved into understanding typical as *most common* and finally typical as *representative of the population.*

Finally, Watson and Moritz (2000a) studied how students construct the concept of a sample. These researchers interviewed 62 students in Tasmania, Australia, who were in grades 3, 6 and 9, using open-ended questions. They also analyzed written responses to a questionnaire. The researchers identified six categories of responses and classified them hierarchically in relation to increasing sophistication of developing concepts of sampling. The researchers emphasized that students do not make sense of statistical samples until they can make sense of populations as real entities. Watson and Moritz argued:

> Students initially build a concept of sample from experiences with sample products or in medical and science-related contexts, perhaps associating the term random with sampling. As students begin to acknowledge variation in the population, they recognize the importance of sample selection, at first attempting to ensure representation by predetermined selection but subsequently by realizing that adequate sample size coupled with random or stratified selection is a valid method to obtain samples representing the whole population. As valid methods of sampling are consolidated, sample data are interpreted with appreciation of how sample size and selection contribute to biased or representative samples. (Watson & Moritz, 2000a, p. 15)

A developmental path can be established based on the literature reviewed in this section: an early precursor to understanding representativeness is the ability to recognize a data set as an entity. Evidence of the developmental nature of representativeness comes from studies on how children's understandings of *average*, *typical* and *sample* develop over time. Underlying the development of these three notions is the gradual development of the ability to treat a data set as an entity. Children's notions of *average* as mode and algorithmic procedure, *typical* as reasonable, and *sample* as random develop with the development of their notion of data set until eventually they can integrate a notion of representativeness into these concepts.

Controlled experiments. Young children are capable of thinking scientifically. Duschl et al. (2007) argued that children are far more competent in their scientific reasoning than was previously suspected. They claimed that the development of scientific reasoning is enhanced by prior knowledge, experience and instruction. Along the same lines, Brewer and Samarapungavan (1991) provided evidence that young children possess basic scientific reasoning. They argued that children do adopt a rational approach in dealing with the physical world, yet they lack the knowledge and experience both in the substantive science and the experimental methodology that more mature scientists have acquired through formal science instruction.

There is some evidence that young children can understand the notion of controlled experiments. Chen and Klahr (1999) explored the conditions under which second, third and fourth grade students can learn and transfer control of variables strategy (CVS). The researchers reported that the students were capable of gaining a genuine understanding of CVS as well as transferring the strategy when designing and evaluating simple tests. Toth, Klahr, and Chen (2000) translated the psychological laboratory findings on children's learning and transfer of CVS reported by Chen and Klahr (1999) into a classroom situation. The researchers developed a benchmark lesson and engaged Grade 4 students in CVS learning. The results from the classroom study confirmed the findings of Chen and Klahr (1999). The researchers reported that the expository instruction used during the intervention was an effective way of teaching CVS. Moreover, students were able to perform controlled experiments and provide valid justifications and evaluations for their designs and those of others.

Gott and Duggan (1998) argued that there is a body of knowledge that underlies scientific evidence and that students need to be taught this body of knowledge explicitly if they are to evaluate scientific evidence. These researchers considered the concept of the variable (independent variable, dependent variable, correlated variables, categoric variables etc…) to be an important concept of evidence that students need to master. Other researchers have also highlighted the importance of explicitly teaching the concept of controlled variables. Strand-Cary and Klahr (2008) investigated the immediate and longer term consequences of explicit teaching of CVS to Grade 3, 4, and 5 students. Students were taught using direct instruction and discovery learning. As part of an immediate assessment, more students learned CVS through direct instruction than through exploration. However, based on reassessments after 3 months as well as after 3 years, the researchers concluded that what the students learned, rather than how they learned it, was a better predictor of far transfer.

Researchers have noticed developmental differences between young children and older ones in terms of their ability to transfer CVS knowledge to new situations. Chen and Klahr (1999) noticed developmental differences in second, third and fourth graders' abilities to transfer the strategy. Second graders were able to transfer CVS only to very near situations. Third graders were able to transfer CVS to very near or near situations. Fourth graders were able to transfer CVS to remote situations.

Developmental differences in scientific reasoning were also reported by Klahr, Fay, and Dunbar (1993), who worked with 64 participants ranging from third graders to college students. The participants were provided with a programmable robot. They were then given a new operation and a hypothesis, which was always incorrect but was either plausible or implausible. The participants were asked to conduct experiments to discover how the new operation worked. The researchers reported that the children, unlike the adults, focused mainly on plausible hypotheses and were unable to induce implausible but correct hypotheses from the data.

Based on the literature reviewed above, a developmental path can be traced for controlled experiments: young children adopt a rational approach in dealing with the physical world. The development is enhanced by prior knowledge, experience and instruction. Despite lacking knowledge and experience in substantive science and experimental methodology, students can understand the notion of controlled experiments as early as in the first years of elementary school and can transfer the control of variables strategy to near situations. With time children develop the ability to transfer the strategy to remote situations.

Credibility of sources. Children draw information from a range of sources (Duschl et al., 2007). Harris (2002) claimed that children draw information from their own perceptions and from the testimony of other children and adults. Duschl et al. (2007) reported that 2-year-old children make basic distinctions in the sources from which they gather information, while children at the ages of three and four acquire a sense of the credibility of reports. Kuhn and Pearsall (2000) argued that 4-year-old children begin understanding that assertions generated by the human mind are distinguishable from an external reality.

Dutt-Doner, Cook-Cottone, and Allen (2007) explored the nature and development of skills that aid Grade 5 and 7 students in analyzing primary source documents in history. The researchers found that factors that contributed to the successful use of documents involved the students' background knowledge, document analysis skills, ability to integrate background knowledge, and historical thinking. The researchers also reported that students had naïve views about the nature of historical understanding and about the ways in which historians use primary source documents to interpret history; all of the students thought there were correct answers out there and that they were supposed to find them out. Finally the researchers claimed that they had detected developmental differences between fifth and seventh graders. Differences included levels and use of background knowledge, image analysis skills and written document analysis skills. Moreover, unlike seventh graders who sometimes questioned the credibility of the source, fifth graders rarely suggested other primary sources to find additional information and considered each primary source to be true.

Hill and Pillow (2006) provided evidence that there are age differences regarding children's understanding of reputations. The researchers read stories to kindergarten, Grade 2 and Grade 4 students involving characters who performed pro- or antisocial behaviors. The researchers then asked the children to judge how various peers viewed the characters. Children in all age groups understood that firsthand experience influenced peer opinions. Grade 2 and 4 students were able to understand the role of indirect experience such as gossip as a factor that may have contributed to one's reputation.

A developmental path for the credibility of sources could be as follows: children draw information from a range of sources and make basic distinctions of these sources. Gradually they acquire a sense of credibility of reports and begin understanding that assertions are human constructions. Children move from considering a source to be true to developing the ability to question the credibility of sources. Moreover, they develop understanding of reputation over time.

Discussion. In this section I presented an example of how one of Ennis's concepts of critical thinking and its associated sub-concepts contribute to the construction of a learning progression. As mentioned earlier, the example needs to be considered a work in progress.

A number of assumptions are made in this section. First, developing understandings on the four sub-concepts discussed above is a pre-requisite for developing understandings of causal generalizations. Second, developing such understandings places the learner in a better position to understand Ennis's criteria for evaluating causal generalizations. Third, developing such understandings places the learner in a better position to engage in meaningful discussions about and with causal generalizations. These assumptions are open for empirical research.

Based on a review of the literature on children's developmental journey regarding the four sub-concepts of causal generalizations, trends likely to contribute towards building learning progressions are identified. These trends are working hypotheses that need to be supported further by developmental research. When the progressions are described more clearly, longitudinal studies can be designed to test the validity of these progressions (Corcoran et al., 2009; Smith et al., 2004).

The literature points to the direction that by the time students reach secondary school, they are developmentally ready to engage in a critical discussion about and with causal generalizations. Certainly, this claim is open for empirical research. The research findings reported in Chapter 6 bring some support for this claim.

My main purpose in this chapter was to explore a developmental approach for the CT-NOS framework. In particular, I studied the possibility of developing learning progressions for NOS in school science. I argued that critical thinking rather than the substantive content of NOS needs to be placed across a developmental trajectory. After critically evaluating King and Kitchener's (1994) developmental model of reflective judgment and Kuhn's (1999) developmental model of critical thinking, I discussed how Ennis's theory of critical thinking can contribute towards developing learning progressions for critical thinking. I ended the chapter with an example showing the likelihood of one of Ennis's concepts of critical thinking contributing towards building learning progressions for NOS in school science.

Chapter 6

Teachers' Views of a Lesson Prepared Using the CT-NOS Framework

Background

In this chapter I present a study evaluating experienced secondary science teachers' views of a NOS lesson that was prepared using the CT-NOS framework. The reason for engaging in this study was to determine the practical viability of the theoretical ideas developed throughout this dissertation. Thus, the purpose of this study was to explore the extent to which the theoretical ideas have the potential to be used. The assumption was that if the ideas receive support from stakeholders – science teachers in this particular case – then they will have a higher potential for use. Accordingly, the results of this study help us to evaluate the possibility of developing a long-term research and development agenda based on the theoretical ideas in this dissertation.

The following four questions were raised in particular: (a) To what extent do experienced secondary science teachers find the NOS lesson that was prepared using the CT-NOS framework feasible, useful and interesting? (b) What features of the lesson do experienced secondary science teachers find feasible, useful, interesting and non-feasible, non-useful and non-interesting? (c) What recommendations do experienced secondary science teachers have to make the NOS lesson more feasible, useful and interesting? and (d) How do the teachers' judgments and recommendations speak to the solutions of the three problems that I have highlighted in this dissertation? These solutions, the reader will recall, are as follows: NOS in school science needs to explicate and target both NOS as an educational end and NOS as a means for socioscientific decision making, it needs to have critical thinking as its foundational pillar, and it must provide a developmental pathway for NOS learning using critical thinking as a progression unit.

Science teachers are one group of stakeholders who might be potential users of educational resources and materials prepared using the CT-NOS framework. The educational resource package prepared for this study was a prototype constructed in order to get feedback. In this study, I was able to acquire professional input from practitioners for the purpose of improving the quality of the educational resources, and the teachers were able to develop professionally as a result of their interactions with the research. The research was conducted in Beirut, Lebanon, and the plan for the study was reviewed for its adherence to ethical guidelines and approved by a research ethics board at the University of Alberta.

A framework proposed by Nistor, Dehne, and Drews (2010) was used to evaluate experienced science teachers' views of a NOS lesson prepared using the CT-NOS framework. The experienced science teachers were regarded as partners in the production of the educational resources in question. Nonetheless, the framework utilized in the present study diverges from Nistor et al.'s framework in that not all of the feedback received from the participating teachers led into product modularity, or changes in the resources as products. Some of the feedback received was used to generate recommendations for in-service science teacher education and curriculum development.

Participants

Convenience sampling was used to select participants. Seventeen experienced secondary science teachers from two schools in Lebanon participated in this study. The decision to involve *experienced* science teachers was based on the idea that if teachers are to be viewed as partners in developing the educational resources, it is imperative that they have broad experiences upon which to draw. Experienced secondary science teachers were defined as having a minimum of 5 years of science teaching experience in a secondary school (Grades 10, 11, and/or 12), holding at least a bachelor's degree in any science field, and holding a teaching degree or an equivalent diploma or certificate. Teachers with a minimum of 15 years of science teaching experience at the secondary level did not need to hold a teaching degree or an equivalent diploma or certificate. The schools were not representative of the population of schools in Lebanon. A description of the schools is provided below. It is crucial to note that the teacher profiles generated from this study may only be generalized to similar contexts and situations.

School A is a private, non-for-profit, coeducational, boarding and day school in the Greater Beirut area. The school offers the Lebanese program for Lebanese students, and an International program for non-Lebanese students and a number of Lebanese students who hold dual citizenship. Sixty-five percent of the student population were enrolled in the Lebanese program, while 35% were enrolled in the International program. The International program leads to a High School Diploma and students have to sit for the British IGCSE. Some students also sit for the GCE AS/A levels. School B is an independent coeducational day school with two campuses, both in the Greater Beirut area. Lebanese and International programs are offered on both campuses. The students come from 20 different countries. Lebanese students are enrolled in the Lebanese program, and foreign students and some Lebanese students having dual citizenships are enrolled in the International program, which offers a High School Diploma preparing the students to sit for SAT I, SAT II and TOEFL. Advanced Placement (AP) courses are also offered in this program for students who wish to pursue college-level studies while at school.

Letters of initial contact were sent to the principals of School A, School B's Campus 1, and School B's Campus 2 (see Appendix F). I also met with the principals and discussed with them the objectives of the study. The principals helped to identify the teachers at their schools who met the recruitment criteria and placed me in contact with their respective science departments. Letters were sent to potential participants inviting them to participate in the study; this involved attending a 4-hour professional development workshop, filling in a questionnaire, and being interviewed (see Appendix G). Invitation letters were also sent to secondary science teachers at these schools who did not meet the recruitment criteria (e.g., teachers with less than 5 years of teaching experience) so that they could attend the professional development workshop as non-participants. Participation for everybody was on a voluntary basis.

In total, 17 experienced science teachers participated in this study (eight males and nine females). Table 2 represents the number of years of school teaching experience of the participants. Table 3 presents the years of science

Table 2

Number of Years of School Teaching Experience of the Participants

Number of Years	Number of Teachers
5 – 9	4
10 – 14	4
15 – 19	4
20 – 24	4
25 – 30	1

Table 3

Number of Years of Science Teaching Experience of the Participants at the Secondary Level

Number of Years	Number of Teachers
5 – 9	8
10 – 14	1
15 – 19	3
20 – 24	4
25 – 30	1

Table 4

Distribution of Science Subject Areas Taught by the Participants

Subject Area	Number of Teachers
Chemistry	8
Biology	8
Physics	5
General Science	1
Health / Nutrition	1

Note. The total number of teachers exceeds 17 because of the presence of teachers who teach more than one science subject area.

Table 5

Traditions of Universities Attended by Participants

University Tradition	Number of Teachers
American	8
Lebanese	6
Arab	1

Note. Participants' highest degrees were taken into consideration. Two participants who were graduates from universities outside Lebanon were excluded.

Table 6

Distribution of Participants as a Function of Their Highest University Degrees in Sciences

Highest Degree	Number of Teachers
Master of Science	4
Diplôme d'études Approfondies	1
Maitrise	2
Bachelor of Science	8
License	2

teaching experience held by the participants at the secondary level. The average years of school teaching experience of the participants was 15.1, while the average years of science teaching experience at the secondary level was 12.8. Table 4 presents the distribution of science subject areas taught by the participants.

Fifteen of the participants were graduates from universities in Lebanon. Two participants were graduates from universities outside Lebanon (one in Canada and one in the USA). BouJaoude and Abd-El-Khalick (2004) claim that institutions of higher education in Lebanon fall under four academic streams having different identities and traditions. These are the French, American, Lebanese and the Arab universities. The fifteen participants of this study who were graduates of universities in Lebanon came from three of the four traditions. Table 5 depicts the traditions of universities attended by participants. Table 6 presents the distribution of participants as a function of their highest university degrees in sciences. Finally, as it is not necessary to have a teaching degree, diploma or a certificate to teach in Lebanon, only eight teachers held teaching degrees, diplomas or certificates.

Data Collection

I prepared a 4-hour-workshop the purpose of which was to introduce the teachers to the NOS lesson prepared using the CT-NOS framework. The workshop used a learning cycle in which the participants were (a) asked to play the role of students and engage in the NOS lesson (exploration phase), (b) guided to reflect on the lesson with the purpose of identifying the characteristics of the lesson and ultimately the CT-NOS framework (introduction phase), and (c) asked to work in groups and develop a mock lesson based on what they had learned (application phase). The workshop was targeted to all secondary science teachers at the schools whether or not they met the recruitment criteria for the research study or agreed to participate in the remaining parts of the study.

I conducted the same professional development workshop separately for the teachers of School A, School B (Campus 1) and School B (Campus 2). The workshop date, time and location were determined by the respective science departments of each of these schools. Two of the workshops were conducted in December 2011 and one in January 2012.

After the workshops, only the teachers who had been recruited to participate in the research project and who had agreed to be part of the study were asked to complete a questionnaire (Appendix H). The other teachers were asked to leave the room. The questionnaire contained a list of open-ended questions that aimed at collecting qualitative data to elicit (a) feasible / useful / interesting features of the lesson, (b) non-feasible / non-useful / non-interesting features of the lesson, and (c) recommendations for improvement. The completion of the questionnaire required about 40 minutes.

During the following weeks I contacted the participants and arranged separate meetings with each of them for follow-up interviews. Sixteen of the 17 participants were interviewed. The interviews were semi-structured and the questions asked were related to the responses that the teachers had provided on the questionnaires with the purpose of acquiring further clarifications on their views. All interviews took place at the schools, lasted about 25 minutes and were audio recorded and later transcribed.

Variables

Three sets of variables were explored in this study:

The first set included (a1) feasible aspects of the NOS lesson, (a2) non-feasible aspects of the NOS lesson, and (a3) recommendations to make the lesson more feasible.

The second set included (b1) useful aspects of the NOS lesson, (b2) non-useful aspects of the NOS lesson, and (b3) recommendations to make the lesson more useful.

The third set included (c1) interesting features of the NOS lesson, (c2) non-interesting features of the NOS lesson, and (c3) recommendations to make the lesson more interesting.

The NOS Lesson

In recent years a number of science educators have conducted intervention studies in which they have guided students to engage in explicit and reflective NOS-related discourse following some form of an inquiry-based activity. Examples of such activities include inquiry-based lessons (e.g., Khishfe & Abd-El-Khalick, 2002), science research internship (e.g., Schwartz et al., 2004), science apprenticeship programs (e.g., Bell et al., 2003) and science laboratory work (e.g., Hsu, Van Eijck, & Roth, 2010; Yacoubian & BouJaoude, 2010). In all of these studies, the researchers have incorporated elements of scientific inquiry in the background lesson based on which a discussion of NOS could follow.

In the present study, reading in the context of science was chosen to be the element of scientific inquiry that would serve as the background context of the NOS lesson. Reading (and writing) occupy most of the working time of scientists (Tenopir & King, 2004) and from this perspective, as Norris & Phillips (2003) have claimed, reading in the context of science is not merely a functional tool for doing science; it is constitutive of science.

Scientific writing has a particular genre. Primary scientific literature is the genre that scientists use to communicate their findings with other scientists (Falk, Brill, & Yarden, 2008). Norris, Macnab, Wonham, and de Vries (2009) claim that the primary scientific literature contains jargon and technical language specific to the area of research and often is not comprehensible by non-scientists including science teachers and school students.

There has been some recent work in adapting primary literature into a form that is understandable by school students at the secondary level. This educational genre, referred to as the adapted primary literature (APL), is designed to enable the use of research articles for science learning at the secondary level (Falk et al., 2008). Yarden, Brill, and Falk (2001) describe the adaptation process as follows: The canonical form is kept as intact as possible; the Introduction is modified to give the novice reader basic background information; the main principles of the Methods are described; the Results are kept authentic, although results not related to the main research questions are removed; the main figures are kept, with slight modifications; and, finally, the Discussion section is expanded as needed so that students can understand it more easily (Yarden et al., 2001).

Research shows that secondary students tend to pose questions that reveal a higher level of critical thinking when they learn science through APL (Brill & Yarden, 2003; Falk, Brill, & Yarden, 2005; Norris, Stelnicki, & de Vries, 2011). In terms of developing NOS understandings, Baram-Tsabari and Yarden (2005) showed that secondary biology students who read an APL text better understood the nature of scientific inquiry and raised more scientific criticism of the researchers' work than did students who read a popular scientific text. Considering these findings, a decision was made to use APL texts as the scientific inquiry context upon which teaching and learning of NOS could be based.

I chose a health-related topic, namely the health effects of low-intensity electromagnetic radiation from cell phones, for participants to defend a position on a socioscientific issue. The participants were guided to formulate an answer to the following question: Should cell phone usage be regulated by law? This question could be addressed from multiple perspectives (politics, policy, environment… and also NOS). The focus was on the NOS perspective.
The choice of the topic was based on the fact that there are relatively few scientific studies on the relationship between long-term cell phone usage and the risk of developing brain tumors. Moreover, the findings do not point to a clear conclusion (Ahlbom et al., 2009; Khurana et al., 2009). Hence, the topic could create a good context for NOS discussions. Furthermore, the substantive science content underlying this topic (e.g., electromagnetic radiation, brain anatomy) is usually taught at the secondary level. Finally, the object that is highlighted (cell phones) is part of the daily lives of the participants making the topic relevant and concrete to them.

I chose two articles that were published in the same year in peer-reviewed epidemiological periodicals (Ahlbom et al., 2009; Khurana et al., 2009). These two groups of researchers have performed meta-analyses of studies published to that date. Despite the fact that they had access to the same data sets, they have arrived at somewhat contradictory conclusions. I adapted these two articles following Yarden et al.'s (2001) approach. Modifications were made to the introductory sections to make sure that secondary students would be provided with the necessary background so that they could understand the terms that were used in these sections. For instance, a whole paragraph was added to introduce electromagnetic radiation and definitions were added next to the terms "latency period" and "short induction" upon their first use. Background information and descriptions of key methodological principles were added in order to make those principles comprehensible to secondary students. For instance, descriptions of a "case-control study" and a "cohort study" were provided. A description of odds ratio (OR), what it measures, and how to interpret OR values was added to the methodology section because the research papers dealt primarily with OR as their statistical tool. The results and the tables were summarized in order to ensure that they focused only on the main research question. The primary articles used a 95% confidence interval (CI) as part of their analyses in addition to the OR values. In the APLs only the OR values were reported, and the CI values were excluded. The discussion sections were also modified to make them understandable to secondary students. Finally, the references section was adapted: a list of references used in adapting the primary literature was added to the already existing list. The APLs were read by an epidemiologist to make sure that the substantive content was kept intact and accurate. Copies of the adapted primary articles can be available upon request.

After adapting the primary literature, I used the APLs to develop a NOS lesson (Appendix I) using the CT-NOS framework. It is important to note that the NOS lesson is not intended to be covered in one session. About four to five sessions are required in order for participants to engage in thorough discussions. The lesson can serve as a unit of work – in physics, for instance – in order to give learners ample time to cover the material. Two components were integrated into the lesson: *critical thinking about NOS* and *critical thinking with NOS*. Given that the studies reviewed by the APLs were mostly case-control epidemiological studies, they were used to guide participants (1) to explore different methods of doing science in addition to experimentation and (2) to think about causal generalizations and explore the circumstances in which causal generalization between variables can be strongly supported. These are NOS-related issues which encourage students to *think critically about NOS*. My goal was to guide the participants to develop understandings of case-control studies and causal generalizations.

Once understandings of case-control studies and causal generalizations are acquired, students are asked to evaluate the extent to which evidence supports a relationship between long term cell phone usage and the risk of brain tumors, and eventually to make an argument that could be used to defend a position on whether or not cell phone usage should be regulated by law. The focus is on *thinking critically with NOS understandings* while making an argument on a science-based social issue. Appendices B to E include some of the handouts prepared using Ennis's (1996a) work that were provided to the participants during the workshops.

Pilot Study

Prior to the professional development workshops, I conducted the same workshop with a group of seven science teachers not participating in the study. This pilot provided practice for me and feedback to make necessary modifications to the workshop. In order to increase the content validity of the questionnaire, the teachers participating in the pilot study were asked to complete the questionnaire and three of them were interviewed in order to check their understanding of the questions and accordingly to make necessary changes.

Data Analysis

Data from the questionnaires and transcribed interviews were analyzed qualitatively using Miles and Huberman's (1994) approach to identify features of the NOS lesson highlighted by the participants when making their evaluations. Miles and Huberman take a realist position; specifically, they describe themselves as subscribing to "transcendental realism" (p. 4) and highlight the need of "methods that are credible, dependable and replicable in *qualitative* terms" (p. 2). They write:

> [W]e think that social phenomena exist not only in the mind but also in the objective world – and that some lawful and reasonably stable relationships are to be found among them. (Miles & Huberman, 1994, p. 4)

Miles and Huberman's (1994) data analysis approach is based on systematically performing three interwoven activities: data reduction, data display, and conclusion drawing and verification. They argue that these three activities should take place in parallel before, during and after data collection.

Following Miles and Huberman's (1994) recommendations, preliminary data analysis during the data collection included reading immediately the participants' responses to the questionnaires. A contact summary sheet (A) was produced for each participant; on it, I reflected on the main issues and themes in each questionnaire. I also planned for further questions that I could ask during the interviews. A second contact summary sheet (B) was produced for each participant after the interviews; on it, I recorded my reflections based on each interview. The first set of contact summary sheets helped me to plan for the follow-up interviews. Both sets helped me perform further analysis of the data at a later stage. A sample contact summary sheet is contained in Figure 2.

Next, the features of the NOS lesson referred to by the participants were coded. Miles and Huberman consider codes to be efficient devices for data-labeling and data-retrieval. A provisional list was developed, but the process of creating the codes extended throughout data analysis, as empirically driven codes were created over time. The codes were placed as marginal remarks on both the teachers' responses to the questionnaires and the transcribed interviews. The final list of names and definitions of codes are presented in Table 7.

Figure 2. Sample Contact Summary Sheet

Contact Summary Sheet

Participant number *10*

Contact Type:		Site	*(school name)*
Questionnaire	*X*	Contact date	*December 21st, 2011*
Interview	________	Today's date	*December 23rd, 2011*

1. Main issues or themes that struck me in this questionnaire/interview
- *Time is a major issue that influences feasibility of the NOS lessons.*
- *Using substantive content already addressed in the curriculum increases the feasibility of the lessons.*
- *The fact that the two research articles are controversial is a problem for this participant. He is recommending me to use less controversial and more conclusive type of articles.*
- *Not all students would find the lessons useful.*
- *Relevance to everyday life is a factor that this participant thinks makes the lesson interesting.*

2. Summary information that I got (or failed to get) on each of the target questions
- *The participant finds the NOS lesson to be moderately feasible (interesting discussion, substantive content aligned with the curriculum; however too controversial and time consuming).*
- *The participant finds the NOS lesson to be useful for some students (critical thinking about NOS) but not useful for others (school age children might get confused and think that credible scientific facts are not that credible anymore). The participant's recommendation on how to make the lesson useful for everyone is not clear to me.*
- *The participant finds the NOS lessons somehow interesting. Interesting because the substantive content is related to everyday life and makes students engage in dialogue and critical thinking. Not interesting because of the inconclusive nature of the readings. His recommendation to make the lesson more interesting is vague.*

3. Anything else that struck me as salient, interesting or important in this questionnaire/interview
- *The participant relates the controversial aspect of the two researches to feasibility, usefulness and interestingness of the lessons. The deeper reasons are still unclear to me.*
- *The participant focuses mainly on the substantive content of the readings in the questions. He has limited input about the NOS discussions that we had at the workshop.*

4. New or remaining questions that I need to consider to ask this participant during the follow-up interview
- *Why is time a factor that makes the NOS lessons less feasible?*
- *How and why are showing the students controversial research findings a problem?*
- *Ask this participant to clarify and elaborate his recommendations.*
- *Remind this participant the NOS discussions that we had and ask to what extent his evaluations are applicable to the NOS discussions versus the background part of the lesson.*

Table 7

Codes for Features of the NOS Lesson

Code	Feature
ali	alignment (or its lack of) between curriculum and the NOS lesson
ass	assessment does not target NOS
con	controversial elements involved in the NOS lesson
cri	critical thinking
cri-a-nos	critical thinking about nature of science
cri-w-nos	critical thinking with nature of science
dec	decision making
det	details
dif	difficulty level
dis	discussions/collaborations/debates
eff	efficiency
eng	engaging
fea +	feasible
fea -	non-feasible
fea +/-	somewhat feasible
int	interesting
int -	not interesting
int +/-	somewhat interesting
int-lev	interesting to some – depends on the abilities and interest of students
lan	language
lev	learning levels and/or various needs of students in the same class
nos	‘nature of science’-related content
pre	preparation for teaching
rea	reading
rec	recommendation
rel	relevant to students’ lives
rep	respecting various positions
res	resources
sci	scientific content knowledge
siz	class size
soc	social awareness
str	structure and organization of the NOS lesson
tim	time
uni	uniqueness of student NOS perspectives
use +	useful
use -	non-useful
use +/-	somewhat useful
use-lev	useful to some – depends on the abilities and interest of students

After the coding was complete, illustrative displays were constructed in the form of checklist matrices using the participants' responses to the questionnaires as well as the interviews. These checklist matrices were descriptive in nature. They constituted the bases for further analyses which resulted in a second set of matrices having an explanatory function. Conclusions were derived at several stages of the data analysis by noting patterns, clustering, subsuming particulars into the general, counting, making comparisons, generating themes, and building logical chains of evidence.

Results

This section reports the results of the study based on analyzing the participants' responses to the questionnaires and the follow-up interviews.

Feasibility of the NOS lesson. The majority of the participants found the NOS lesson to be somewhat feasible for inclusion in a secondary level science course (Table 8). Table 9 shows the features of the NOS lessons that the participants thought made the lesson feasible and those that made it non-feasible. Table 10 highlights every feature that was raised by at least four participants and illustrates sample responses.

Usefulness of the NOS lesson. Table 11 shows that all participants found the NOS lesson to be either useful or somewhat useful. The participants also believed that their students would find the NOS lesson useful, somewhat useful or useful depending on their abilities and interests (Table 12). Table 13 shows the features of the NOS lesson that the participants thought made the lesson useful

Table 8

Number of Participants in each Feasibility Category

Feasibility Category	Number of Participants
fea +	1
fea +/-	15
fea -	1

Note. Definitions of feasibility categories are found in Table 7.

Table 9

The Feasibility and Non-Feasibility of Features of the NOS Lesson as Identified by the Participants

	Features																
Part.	rel	ali	nos	cri	eng	int	lan	dif	res	str	tim	pre	siz	con	ass	lev	rea
1	+	+							-		-					-	
2				-			+			+						-	
3		+							+		-						
4	+			-							-					-	-
5							+	+			-	-					
6	+			-			-	-			-					-	
7			+								-						
8	+					+								-			
9	+	-		+							-						
10		+	-			+					-			-			
11					+						-				-		
12				+							-			-	-		
13	-													-			
14			+	+										-			
15											-			-			
16		+									-	-	-				
17	+	-															

Note. Definitions of features are found in Table 7; + denotes a feature that makes the NOS lesson feasible; - denotes feature that makes the NOS lesson non-feasible.

Table 10

Sample Participant Responses Concerning Feasibility for Each Feature Referred to by at Least Four Participants

Features	fea+	fea-	Recommendation to make the lesson more feasible
rel	[The lessons are] related to our everyday life problems or issues that can somewhat enhance the curiosity of students to know more (Q4).	They [the studies] are projected onto a certain type of countries and cannot be generalized (Q13).	To generalize these studies (Q13).
ali	The idea of e.m.r. [electromagnetic radiation] is already mentioned in many physics books (Q10).	… it can't be applied in the course I teach (Q9, I9).	Include NOS objectives in the curriculum (Q1). Prepare different methods to start different chapters or topics (Q17).
cri	We can lead our students to critical thinking during explanation in class… (Q9, I9).	These lessons require analysis skills which some students might be weak at (Q2). Some students are not able to analyze articles, compare and contrast results (I6).	To make the lessons feasible for everyone, the teacher should guide the students in all the parts especially those related to tables and drawing conclusions from data (Q2).
tim		…time limitations imposed by closed ended curriculum set by the Ministry of Education (Q16). Could be introduced in class if you have enough time to discuss, analyze or 'critically think' at a certain level (Q10).	Two teachers (eg biology and physics teachers) involved in one lesson? (Q1). Introducing Ct-NOS with an easier (simple) research so students won't have or spend a lot of time on the background information in order to engage in the research (Q5).

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	It might be feasible but not for classes that have official exams as it is time consuming (Q12).	Class duration, number of periods per week should be increased (Q12).
con	The contradictory conclusions reached even when based on the same data might confuse students (Q8). … They are not up to the level where they can manipulate different criteria. They need to memorize something (I8). … too controversial! Would leave students with the impression that science is not able to reach results conclusively (Q10, I10).	Select a less controversial idea, where we could teach the nature of science using much older research that is more conclusive than cellular phone usage which hasn't been studied enough (Q10).
lev	Presence of students with learning difficulties (e.g. dyslexic) (Q1). … difficulty to meet the different levels and intellects of students in the same class (Q4).	Adapt the articles to students with learning difficulty who we believe we could do a great deal of critical thinking (eg more diagrams/pictures, less reading) (Q1). Lesson should include more pictures, graphs, videotapes (real cases) (Q6).

Note. Definitions of features are found in Table 7; Q = Questionnaire, number following Q represents participant number; I = Interview, number following I represents participant number.

and those that made it non-useful. Table 14 shows the features of the NOS lesson that the teachers believed their students would find useful or not useful. Finally,

Table 11

Number of Participants in each Usefulness Category

Usefulness Category	Number of Participants
use +	10
use +/-	7
use -	0

Note. Definitions of usefulness categories are found in Table 7.

Table 12

The Extent to Which Participants Think Their Students Would Find the Lessons Useful

Usefulness Category	Number of Participants
use +	6
use +/-	7
use -	0
use-lev	4

Note. Definitions of usefulness categories are found in Table 7.

Table 15 highlights every feature in Tables 13 and 14 that is raised by at least four participants and illustrates samples from their responses.

Interestingness of the NOS lesson. Most participants found the NOS lesson to be interesting and a few of them found the lesson to be somewhat interesting. No participant found the lesson to be not interesting (Table 16). As concerns the extent to which participants think their students would find the NOS lesson interesting, their responses were distributed among believing that their students

Table 13

Useful and Non-Useful Features of the NOS Lesson as Identified by the Participants

Part.	Features														
	eng	cri-w-nos	cri-a-nos	cri	dec	sci	soc	rel	dis	nos	con	rea	str	dif	ass
1		+	+	+						+					
2			+	+											
3				+											
4				+						+					-
5			+	+							+			-	
6				+		+		+		+					
7				+							+				
8	+			+				-							
9	+			+		+		+	+				-		
10			+			+					-				
11	+			+	+							-			
12						+		+				-			
13								+			-				
14			+	+							-				
15				+											
16	+			+		+	+								
17	+	+			+										

Note. Definitions of features are found in Table 7; + denotes a feature that makes the NOS lesson useful; - denotes a feature that makes the NOS lesson non-useful.

would find it interesting, somewhat interesting, non-interesting, and interesting depending on their abilities and interests (Table 17). Table 18 shows the features of the NOS lessons that the participants thought made the lesson interesting and those that made it non-interesting. Table 19 shows the features of the NOS lesson that the teachers believed their students would find interesting or non-interesting. Table 20 highlights features from Tables 18 and 19 and illustrates sample participant responses.

Table 14

Features of the NOS Lesson That the Participants Think Their Students Would Find Useful and Non-Useful

	Features																	
Part.	eng	int	dec	rel	cri	dis	rep	lan	cri-a-nos	sci	nos	con	rea	str	det	ass	dif	ali
1				+										+	-			
2	+					+												
3	+										+		+		-			
4				+	+							+						-
5											+	-					-	
6					+					+								
7			+		+				+			-						
8				-		+												
9				+	+							-						
10									+			-						
11	+		+													-		
12				+									-					
13				+				+							-			
14						+	+					-						
15					+	+												
16	+	+	+	+									-					
17	+	+																

Note. Definitions of features are found in Table 7; + denotes a feature of the lesson that teacher thinks students will find useful; **-** denotes a feature of the lesson that teacher thinks students will find non-useful.

Discussion

In this section I discuss the findings of this study relating them to the solutions of the three problems that I have highlighted in this dissertation. Accordingly, I organize the section under three headings: (1) critical thinking as a foundational pillar of NOS in school science, (2) NOS as an educational end and NOS as a means for socioscientific decision making, and (3) developmental

Table 15

Sample Participant Responses for Each Feature of Usefulness Referred to by at Least Four Participants

Features	use+	use-	Recommendations to make the lesson more useful
eng	The lessons are so much useful because they make students get involved more… (Q16, I16).		Make them more engaging (Q17).
cri	… [Critical thinking] is very well needed to raise good citizens (Q1). [The lesson is useful because it] help[s] the student analyze, think, integrate, come up with conclusions on his own. They help him also criticize others' work and not take any information for granted (Q7).		
cri-a-nos	These lessons invite students to develop critical thinking, have a clear picture about cause-effect relation. They are useful in highlighting the causes of difference in results when research is conducted and how to make a conclusion stronger (I2).		
cri-w-nos	The lessons are useful since they force students to think in a critical way using what they learned about causal generalizations in order to find answers to a certain social problem (Q17).		

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sci	learning about new diseases (Q10). the information found in the articles (Q9).		
rel	Every single student nowadays has a cell phone, so they would like to hear more about this topic (Q12, I12).	not involving research taking samples from our community and samples from the students group age (Q8).	Base the work on a wider sample (Q8).
con	The lesson is presenting two different research on the same topic with different conclusions. So it is a good model to represent science or NOS… (QI7).	[Some students] might think that credible scientific facts are not credible anymore (Q10, I10). No decision can be made at the end of the lesson (Q13, I13).	Find less contradictions to point out and focus on the facts more (Q7). Narrowing level of uncontrolled variables and widening the scope/focus on controlled ones (Q14).
dis	the debate (Q9). Students would find collaborative work to be useful (Q14).		
dec	Students would find useful learning about correlation between two variables and the credibility of the sources because these features help in decision making… (I7).		
nos	The lessons are useful because the student will notice that any scientific theory or law can be amended with time due to different aspects or factors that can arise with time or due to changes in technology (Q4).		

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rea	I think students would find how to read and analyze a scientific issue useful (Q3).	Having a lot of info to read by students (Q12).	Minimize the amount of given paper (Q12). Introduce diagrams and charts to facilitate the student's readings of the articles (Q13).

Note. Definitions of features are found in Table 7; Q = Questionnaire, number following Q represents participant number; I = Interview, number following I represents participant number.

Table 16

Number of Participants in each Interestingness Category

Interestingness Category	Number of Participants
int +	14
int +/-	3
int -	0

Note. Definitions of interestingness categories are found in Table 7.

Table 17

The Extent to Which Participants Think Their Students Would Find the Lesson Interesting

Interestingness Category	Number of Participants
int +	9
int +/-	4
int -	1
Int-lev	3

Note. Definitions of interestingness categories are found in Table 7.

Table 18

Interesting and Non-Interesting Features of the NOS Lesson as Identified by the Participants

	Features															
Part.	str	rel	dec	sci	con	eng	cri-a-nos	cri-w-nos	cri	dis	soc	pre	det	tim	rea	dif
1		+								+				-		
2				+												
3	+									-						
4		+							-						-	
5		+											-			
6															-	-
7	+		+				+	+						-		
8					-	+			+		+					
9	+								+	+						
10		+			-				+	+						
11		+		+						+			-			
12		+								+						
13				+									-			
14					-		+									
15					+	+										
16		+	+	+								-				
17	+															

Note. Definitions of features are found in Table 7; + denotes a feature that makes the NOS lesson interesting; - denotes a feature that makes the NOS lesson non-interesting.

factors. The analysis of the results revealed a set of emerging themes, which are discussed here under each of the three headings.

Critical thinking as a foundational pillar of NOS in school science. Three teachers considered critical thinking to be a feature that made the NOS lesson feasible (Table 9). These teachers considered the lesson itself an

Table 19

Features of the NOS Lesson That the Participants Think Their Students Would Find Interesting and Non-Interesting

	Features											
Part.	str	eng	dis	cri-a-nos	cri	det	rel	rea	sci	con	tim	dif
1			+				+					-
2							+					
3			-						+			
4					-		+	-				
5						-			+			
6			+					-				
7		+							-	+	-	
8							+		+			
9			+									
10			+				+			-	-	
11			+		+			+				
12			+			-	+					
13						+	-					
14				+	+							
15												
16		+	+					-				
17	+											

Note. Definitions of features are found in Table 7; + denotes a feature of the lesson that teacher thinks students will find interesting; - denotes a feature of the lesson that teacher thinks students will find non-interesting.

opportunity to engage students in critical thinking (e.g., Q9, I9, Table 10). Three other teachers considered critical thinking to be a feature that made the lesson non-feasible (Table 9). These participants highlighted students' inability to engage in analysis as a factor that affects the feasibility of the lesson (e.g., Q2, I6, Table 10). There may be several reasons why students find difficulty

Table 20

Sample Participant Responses for Each Feature of Interestingness Referred to by at Least Four Participants

Feature	int +	int -	Recommendation to make the lesson more interesting
str	It is interesting as it points out the topic in an organized way (Q7).		Include activities rather than just research work (Q7). Introduce technology (you tube movies, animations) to back up the case studies or the lessons (Q9).
rel	Features that are related to our life may enhance the curiosity of students and so they will be interested to know more (Q4, I4).	The places where the studies took place (Q13).	
sci	There is always something new that's not found in textbooks (Q11).	Students might not be interested in knowing that much information (I7).	
con	Students might find the presence of contradictory facts interesting (Q7).	The fact that different or even contradictory conclusions reached, which might create confusion in the student's mind (Q8, I8).	Focus more on data analysis and agreement on scientists to get a narrow margin for credibility purposes (Q14).
cri	Very interesting since it engaged us in open questions and critical thinking (Q9).	… analyzing graphs, drawing their own conclusions (Q4).	
dis	Students love to give their personal points of view and hear others' points of views (Q1, I1).	My concern if the lessons are going to be only discussion, this can be less interesting for some of the students (Q3).	I think if some of the lessons can be practical not only theoretical or research, the lessons can be more interesting (Q3).

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rea	Reading scientific literature and analyzing it may make them (students) feel as if they've accomplished something (Q11).	Too much reading (Q16).	Introduce subjects that require less readings… (Q16).
eng	[My students would find the lesson] very interesting as it makes them major players in the process of the lesson and that what they think and contribute has an outcome (Q16).		
det	My students would find the details about cell phones and brain cancers interesting (Q13).	When the analysis gets too deep and you start getting into the nitty gritty you lose the essence of the exercise (I11).	Make the lesson simpler maybe (Q5).

Note. Definitions of features are found in Table 7; Q = Questionnaire, number following Q represents participant number; I = Interview, number following I represents participant number.

engaging in analytical reasoning. For instance, there could be motivational factors, factors related to student background and preparation, and factors related to teacher preparation. Participant 2 considered critical thinking to be a non-feasible feature of the lesson, yet acknowledged that the teacher plays a crucial role in helping students. Hence, the participant made the following recommendation:

> To make the lessons feasible for everyone, the teacher should guide the students in all the parts especially those related to tables and drawing conclusions from data. (Q2)

Thirteen teachers considered critical thinking to be a useful feature of the lesson (Table 13). This is an encouraging figure. However, only five of those 13 considered critical thinking to be a feature that their students would find useful (Table 14). Although the rest of the teachers did not think that their students would find critical thinking to be non-useful, they weren't positive either.

Finally, four teachers considered critical thinking to be a feature that makes the lesson interesting (Table 18) and two others thought that their students would find critical thinking to be an interesting feature of the lesson (Table 19). One teacher (Participant 4) thought that critical thinking was a non-interesting feature of the lesson and also thought that students would find it non-interesting (Tables 18, 19). The same teacher had commented that critical thinking was a feature that made the lesson non-feasible, despite finding it useful. In the paragraphs that follow I highlight four trends in the teachers' responses that challenge directly or indirectly the notion of critical thinking being a foundational pillar of NOS in school science.

Vague definitions of critical thinking. During the interviews many teachers provided vague definitions of critical thinking when they were asked what they meant by it.

> *Critical thinking is the way you try to develop what you are learning in order to be applicable (I6)*

Such vague definitions may imply that teachers do not understand the core meaning of critical thinking. Ennis's (1969) "programmatic definition" (p. 179) could be useful in explaining the basis of such vague definitions. Critical thinking is an appealing idea used in school philosophy statements and governmental policy documents. Because of the high status and importance of critical thinking, many teachers have developed a language that applauds the idea without being reflective of what it entails. Ennis argues:

> In effect a programmatic definition is a proposal (that is, a request, or command, or entreaty, etc.) for adoption of a program or a point of view. . . . What is wanted is to attach a particular word to a program or point of view in order to make it more (or less) palatable or in order simply to adjust the emotive aspects of our language to the programs or points of view that have already been adopted. (Ennis, 1969, p. 179)

It was also evident that many participants had difficulty training students for critical thinking. Possibly, because critical thinking is quite a vague construct in the minds of some participants, they find difficulty teaching it. The script below is derived from the interview with Participant 11 which shows how she finds difficulty teaching critical thinking:

> *Researcher: How do you teach for critical thinking?*
>
> *Participant 11: Critical thinking is very difficult to teach. You can only teach critical thinking if you can have them [students] practice. Even if you can sharpen critical thinking in some people I don't think you can teach them as the alphabet.*
>
> *Researcher: Can you please elaborate on that?*

Participant 11: It's one of those things you can improve with time and you can be good at it or sort of average and some people would never make it. (I11)

The findings reported above are quite well aligned with those reported by Bataineh and Alazzi (2009) as well as by Paul, Elder, and Bartell (1997).

Controversial elements. Controversial elements in the NOS lesson make it authentic and establish a context for students to engage in critical thinking. Nonetheless, many teachers considered the presence of controversial elements in the NOS lesson to be problematic. Six teachers thought that the controversial elements decreased the feasibility of the lesson itself (Table 9). Three considered them to be non-useful in the NOS lesson (Table 13) and three considered them to be non-interesting (Table 18). Five believed that students would find the controversial elements in the NOS lesson to be non-useful (Table 14) and one thought that students would find them non-interesting (Table 19). There were two arguments made by these teachers.

The first argument is that the controversial elements of the NOS lesson will confuse students (e.g., Q8, I8, Table 10). Here is a short script from the interview with Participant 8 that illustrates his position further:

Participant 8: I think it is a problem when students will not be able to come up with one simplified conclusion, especially they are not up to the level when they can manipulate different criteria. They need to memorize something. That's why I don't like quantum physics. I find it confusing even to myself.

Researcher: You agreed earlier that we need to teach students that scientific knowledge is tentative; now you're saying that students should not be exposed to contradictions. How do you bring these two pieces together?

Participant 8: If an issue has more than one conclusion, then that should be exposed to students who are at a certain level of intellect who can evaluate the information by themselves. If students are below that standard, then I might not include that.

Researcher: In your current teaching what is the percentage of your students who have reached that threshold in your opinion?

Participant 8: It depends on the class. In years 10 and 11, 20-30% have reached that level. In year 12 the percentage is higher because students choose to go into the life sciences section. (I8)

The second argument is related to the controversial elements of the NOS lesson making students lose their trust in science (e.g., Q10, I10 Table 10).

Students are already very much politicized in our country and tend to drag everything to politics. Many of them have already lost trust in politics and politicians. When you get them to discuss nature of science and how science can have different point of views… some of the students will actually be more skeptical about science and will refuse some of the facts that we consider something trivial. We have to play safe. (I10)

The view that students might lose trust in science as a result of being exposed to controversial issues is raised by science educators (e.g., Driver et al., 1996; Kolstø, 2001a; 2001b). Kolstø (2001a) proposes explicitly clarifying to students the distinction between *ready-made-science*, or what is found in science textbooks and is often non-controversial, and *science-in-the-making*, or the forefront of research which can be controversial.

Participant 7's feedback is worth highlighting in this section. This participant found the controversial elements involved in the NOS lesson useful for students, yet she believed that her students would not find the controversial elements to be useful. She writes:

> *It [the lesson] is presenting two different research on the same topic with different conclusions. So it is a good model to represent science or NOS… [but] they [students] might think that they didn't come up with a conclusion and that it is hard to understand. (Q7)*

Nonetheless, this participant was ready to compromise to ensure that her students would find the lesson useful. She recommended: "find less contradictions to point out and focus on the facts more" (Q7).

Reading. Reading in the context of science was chosen to be the focus of scientific inquiry in the NOS lesson. Norris and Phillips (2003) differentiated between the *fundamental* and *derived* senses of scientific literacy. They highlighted the centrality of text in Western Science and argued that reading (and writing) are constitutive of science and are not merely tools for doing science. From this perspective, reading was viewed in the present study not only as being a tool to facilitate critical thinking among learners, but as inherent to the thinking process itself. Three participants found reading to be a challenge for their students. Instead of thinking about ways to encourage their students to read more, they suggested reducing the amount of reading required as part of the background context of the NOS lesson (e.g., Q12, Table 14). Here is a section from the interview that took place with Participant 6 which illustrates this point:

> *Researcher: I notice that you mention reading would make the NOS lesson less interesting. Why do you say so?*
>
> *Participant 6: Students nowadays do not like reading. They find it a boring activity.*
>
> *Researcher: Why do you think so?*
>
> *Participant 6: It's a general culture thing. Kids are more interested in video games, Internet and chat than in reading.*
>
> *Researcher: How do you address this issue in your science classrooms? Do you assign reading for your students?*
>
> *Participant 6: I feel I'm giving less reading nowadays because the students would not read. I sometimes try to find other ways that can engage the students more in the lesson like hands-on activities.*
>
> *Researcher: Do you think that replacing reading by hands-on activities would work?*
>
> *Participant 6: I think students have different learning styles. A few of them would enjoy reading but others would prefer doing things. As long as my students are achieving the objectives I do not mind changing the means. (I6)*

Clearly, Participant 6 views reading as a tool or a means that one could use in order to engage in science learning. Such a position assumes that reading is merely a tool and is situated outside science.

Time. Treating critical thinking as a foundational pillar of NOS in school science necessitates an appreciation of the importance of NOS in the science curriculum in the first place. Many teachers considered NOS to be of lower priority than other areas of the science curriculum. The majority of the participants considered time to be a factor that may reduce the feasibility of the NOS lesson. Three patterns were identified in the participants' responses regarding time: (1) a pre-determined curriculum setting priorities and controlling time available (e.g., Q16, Table 9); (2) teachers setting priorities, managing time accordingly and viewing the NOS lesson as of secondary importance (e.g., Q10, Table 9); and (3) terminal external examinations imposing priorities and thus indirectly affecting management of time (e.g., Q12, Table 9). These findings are aligned with previous research: the issue of restricted time being a factor influencing teachers' decisions about curricular priorities has been raised by other science educators (Abd-El-Khalick et al., 1998; Abd-El-Khalick & Lederman, 2000b; Hodson, 1993).

NOS as an educational end and NOS as a means for socioscientific decision making. NOS as an educational end refers to thinking critically *about* NOS, while NOS as a means for socioscientific decision making refers to thinking critically *with* NOS. Seven teachers highlighted critical thinking *about* NOS in their responses. Five considered critical thinking *about* NOS to be a useful feature of the NOS lesson (Table 13), two considered it to be a feature that their students would find useful (Table 14), two considered it to be an interesting feature of the NOS lesson (Table 18), and one considered it to be a feature that students would find interesting (Table 19). As for critical thinking *with* NOS, only a few teachers highlighted it in their responses. Two teachers considered it to be a useful feature of the NOS lesson (Table 13) and one considered it to be an interesting feature of the NOS lesson (Table 18).

The distinction between NOS as an educational end and NOS as a means for socioscientific decision making was not a highlight in most of the participants' responses. Although most teachers commented on critical thinking being a useful feature of the lesson, many of them did not differentiate between critical thinking *about* NOS and critical thinking *with* NOS. This is in spite of the fact that the workshop focused consistently on these two elements. Only two teachers (Participants 1 & 7) highlighted both critical thinking about NOS and critical thinking with NOS in their responses and were explicit in the distinction. There were at least four challenges that could have contributed to the fact that teachers did not differentiate between critical thinking about NOS and critical thinking with NOS. Next, I highlight these challenges by reporting on trends identified in the teachers' responses.

Discussions. A number of teachers found the discussions involved in the NOS lesson to be an interesting feature of the lesson (Table 18), and a number of them thought that it is a feature that their students would find interesting (Table

19). Most teachers did not comment that discussions could be associated with the feasibility and usefulness of the NOS lesson. In fact, discussions in the context of the present NOS lesson were intended to engage the participants in critical thinking about NOS and critical thinking with NOS, yet most teachers did not see the connection.

The transferability of critical thinking. A number of teachers defined critical thinking as a general skill or general skills that could be transferred across different situations:

> *Critical thinking is a general skill, you can apply everywhere. You learn how to analyze and you can analyze in every situation. (I9)*
>
> *Critical thinking is to analyze a certain piece of information or to be able to read data and relate factors to each other. . . . When a student learns these skills he can apply them in every subject. (I7)*

Despite the fact that the participants were constantly guided during the workshop to realize the importance of understanding the context when engaged in critical thinking, only a few participants expressed an awareness of the importance of the context during their interviews. Accordingly, unlike the participants who considered critical thinking to be a general transferrable activity, these few participants were explicit about the importance of guiding students to engage in critical thinking *about* NOS (e.g., I2, Table 15) or critical thinking *with* NOS (e.g., Q17, Table 15). The argument made by Participant 14 is worth noting:

> *Critical thinking is about thinking and going in depth in certain issues, analyzing them in order to find if they are valid or not . . . The context of*

the issue is important. You can think critically about the causal generalizations if you know or learn something about them but this does not mean that you will also be good about thinking on some another issue. (I14)

The meaning of the term nature of science. Another challenge that could have contributed to teachers' failure to differentiate between critical thinking about NOS and critical thinking with NOS could be related to their alternative definitions of the nature of science. Despite attending a four-hour-workshop, a number of the participants showed different understanding of the nature of science during the interviews than I had presented earlier. Consider as an example the following script derived from the interview with Participant 16:

Researcher: What would you like to see in a student as characteristics that makes you say that this student has good understanding of nature of science?

Participant 16: I could say that he has good understanding of nature of science if he can relate what he is studying to everyday life. (I16).

Researcher: What does nature of science mean to you?

Participant 16: [pauses]. Nature of science is applying science to everyday life.

Moreover, some participants were unable to differentiate between substantive science content and nature of science:

Researcher: What does nature of science mean to you?

Participant 15: [pauses]. There is no specific definition. I think it is an abstract idea.

Researcher: You mentioned earlier that teaching and learning of the nature of science is important. What do you teach under the title of nature of science?

Participant 15: Chemical change, evolution (I15).

Nature of science and scientific inquiry. Many teachers were unable to differentiate between doing inquiry and reflecting on the inquiry process in spite of the probes that I was giving them during the interviews. Lederman (2004) considers scientific inquiry and NOS to be intimately related and overlapping, yet to him, scientific inquiry is the process by which scientific knowledge is developed, while NOS entails the values and beliefs inherent to scientific knowledge and its development.

Here is an example taken from the interview with Participant 12:

Researcher: Is there a difference between doing observations and thinking about what it means to observe?

Participant 12: [pauses]. Can you please rephrase the question?

Researcher: [pointing to a plant]. What do you observe?

Participant 12: I observe a plant that has green leaves.

Researcher: Great. Now I want you to step out of your experience of observing and reflect on what you just did. Can you think about what you mentally did so that you gave me this answer?

Participant 12: [pauses]. I just observed. Looked at the plant. So maybe the difference is that observing would include just seeing while thinking about observation is when I am trying to discover something new in the plant not just seeing.

Here is another example from an interview where the participant had a hard time differentiating between engaging in scientific inquiry and developing understandings of NOS. This participant does not seem to know about explicit and reflective NOS teaching as a way of fostering NOS understandings among learners. Moreover, she assumes that engaging in inquiry alone is sufficient for her students to construct their NOS understandings – a viewpoint that has been empirically challenged by many science educators (Lederman, 2004).

Researcher: What characteristics should your students show as evidence that you say that they have an understanding of the nature of science?

Participant 4: They have to investigate a certain issue like laboratory work, or research work. But, they should work. They should not depend on the scientists' work. They should indulge themselves in the investigations in order to come up with the conclusions that are coherent with what they know theoretically. They have to go into the investigation themselves (I4).

Engaging in scientific inquiry alone is not sufficient for students to develop their NOS understandings or to use their NOS understandings in socioscientific decision making. One needs to be reflective about the inquiry process itself. Differentiating between NOS and scientific inquiry could help better understand the distinction between NOS as an educational end and NOS as a means for socioscientific decision making.

Developmental issues. Most participants did not comment directly on developmental factors that may contribute to students' engaging in the NOS lesson. One reason might be related to the fact that the participants were all teachers at the secondary level, and the workshop and the NOS lesson focused on the secondary science context. Nonetheless, four teachers thought that student abilities is one factor that may determine whether students will find the lesson useful (Table 12), and three teachers thought that student abilities may determine whether students will find the lesson interesting (Table 17).

If the NOS lesson were not developmentally appropriate, teachers would have commented that it would not be feasible to engage their students in the lesson. In fact, except for one participant, all found the NOS lesson to be either feasible or somewhat feasible for inclusion in a secondary level science course. Among the participants, only four teachers commented that learning levels and/or various needs of students in the same class are factors that reduce the feasibility of the NOS lesson (Table 9). Yet, these teachers were optimistic and recommended adapting the lesson further to reach students with various needs (Q1, Q6, Table 10).

Conclusions and Recommendations

This study explored experienced science teachers' views of a lesson prepared using the CT-NOS framework. The teachers were generally positive about the lesson. The results showed that most participants found the lesson to be somewhat feasible to be taught in a secondary science classroom, useful or somewhat useful to their students, and interesting. The teachers' generally positive views provide grounds for optimism. Despite the huge amount of work required, the theoretical claims developed in this dissertation are worth pursuing further. They have the potential to be bases for a long-term research and development agenda as discussed below and in Chapter 7.

There were a number of features identified in this study that the teachers claimed would make the lesson more feasible, useful, and interesting on one hand or non-feasible, non-useful and non-interesting on the other. These features need to be taken into consideration in attempting to improve the lesson as well as in designing new lessons based on the CT-NOS framework. This study highlighted at least fourteen features of the NOS lesson that make it feasible, useful, interesting or non-feasible, non-useful, non-interesting. Moreover, the participants' recommendations can also be grouped under the fourteen features. These are (1) the relevance of the lesson to the lives of students; (2) the alignment of the lesson with the science curriculum being used; (3) the adaptation of the lesson, in general, and the background context, in particular, to the learning levels and/or the learning needs of various students in the same class; (4) the extent to which the lesson is engaging in nature; (5) the involvement of scientific content knowledge; (6) the involvement of NOS-related content; (7) the involvement of elements that engage students in decision making; (8) discussions; (9) critical thinking; (10) the organization of the lesson; (11) the details of the background context; (12) time limitations; (13) reading required from students; and (14) controversial elements involved in the NOS lesson.

It is important to note that not all features identified by the participants need to be given equal weight while producing new resources based on the CT-NOS framework or reviewing the resource package that was prepared for the professional development workshop. While adapting the background context to the learning levels and/or the needs of various students might be a plausible path to follow, removing controversial elements from the NOS lesson might not be so.

In general, the teachers found critical thinking to be a useful feature of the NOS lesson. However, a generalization regarding the feasibility and interestingness of critical thinking could not be achieved. The study revealed a number of teacher challenges that could have an impact if critical thinking were considered a foundational pillar of NOS in school science. First, many teachers offered vague definitions of critical thinking and had difficulty teaching it. Second, a number of them viewed controversial elements in the lesson to be problematic. Third, some teachers made compromises to have students read less. They did not appreciate the role of reading in scientific thinking. Fourth, most teachers considered NOS to be less important than other areas of the science curriculum.

From another perspective, none of the participating teachers in this study was negative regarding *critical thinking about NOS*. In general, the teachers had more to say about *critical thinking about NOS* than *critical thinking with NOS* and were not attentive to the distinction between them. At least four factors were found that could have contributed to the lack of a distinction. First, most teachers had difficulty recognizing after the workshop that discussions in the context of the NOS lesson had a purpose. Second, a number of teachers defined critical thinking as a general skill or general skills that could be transferred across different situations. Third, many teachers had alternative definitions of the term NOS. Finally, many teachers were unable to differentiate between doing inquiry and reflecting on the inquiry process.

This study reveals at least three lines of professional development needs for science teachers. First, there is a need to provide in-service science teachers with opportunities to reflect on their understandings and teachings of critical thinking. Critical thinking needs to be more concrete and less ambiguous in teachers' minds. The study showed that many teachers did not understand what critical thinking meant; moreover, many of them did not appreciate the importance of understanding the context while engaging in critical thinking. Teachers need to be able to define critical thinking, and to identify the knowledge, skills and dispositions needed while engaging in critical thinking. They also need to be guided so that they can effectively address the development of learners' critical thinking in science classrooms in general and NOS teaching and learning in particular.

Second, opportunities need to be provided for science teachers to engage in critical thinking about NOS as well as critical thinking with NOS. The results of this study showed that a number of teachers had naïve understandings of what the construct of *nature of science* entailed. Moreover, many teachers had problems differentiating between NOS and substantive science content, and a number of them had difficulty distinguishing between engaging in scientific inquiry and reflecting on that experience. There is a need to guide science teachers to be reflective about their own NOS understandings. Professional development opportunities need to be provided in order for them to think critically about their own NOS understandings as well as think critically with their NOS understandings.

Third, guidance needs to be provided for science teachers on how to engage their students in critical thinking about NOS and critical thinking with NOS. The study revealed that many of them did not have the knowledge and skills needed to engage students in NOS learning. Some of them held the view that when students engage in scientific inquiry they will implicitly and automatically learn NOS. Teachers need to be shown results of empirical studies that falsify such claims and need to be trained so that they can effectively guide their own students to engage in critical thinking about NOS and with NOS. From another perspective, many teachers who participated in this study considered time to be a factor that decreases the feasibility of the NOS lesson. There is the need to continue convincing in-service science teachers of the importance of NOS teaching and learning in science education. Teachers need to view NOS teaching and learning as being *integral* to science teaching and learning rather than supplementary. This is not an easy task to accomplish, given several factors that influence teachers' beliefs. These factors are related to teacher preparation and prior experience, curricular priorities, external examinations and so on.

Despite the fact that most participants did not directly comment on developmental aspects related to the NOS lesson, all except one teacher found the lesson to be either feasible or somewhat feasible for inclusion in a secondary level science course. There is a need to develop NOS lessons, using the CT-NOS framework, that are applicable for lower classes and to get feedback from middle and elementary school teachers. Moreover, there is the need to design empirical studies, both cohort and longitudinal, in order to understand developmental factors associated with the CT-NOS framework.

Finally, based on some recommendations from teachers, future NOS lessons need to be developed taking into consideration a wide range of student abilities and needs. This is one factor that could help students of various backgrounds and abilities engage in the NOS lesson. This may also require teachers to consider differentiated instruction so that more students can master the required objectives of the lesson.

Chapter 7

Summary and Conclusions

In this chapter I provide a summary of the present study, tying together its different pieces as a conclusion for my work. I discuss how the study was a contribution *towards a philosophically and a pedagogically reasonable NOS curriculum*. I highlight the main outcomes of the study, discuss its limitations, and propose directions for future research and development. I start by recalling the objectives of this study:

O1 To explore the potential of a NOS curriculum with particular characteristics (as outlined below in O2) as an alternative to consensus frameworks of NOS in school science

O2 To explore how NOS in school science could

1. explicate and target both NOS as an educational end and NOS as a means for socioscientific decision making
2. have critical thinking as a foundational pillar
3. provide a developmental pathway for NOS learning using critical thinking as a progression unit

O3 To synthesize a framework for addressing NOS in school science

O4 To explore developmental possibilities for the synthesized framework

O5 To explore experienced secondary science teachers' views of a lesson prepared using the synthesized framework

In this dissertation I started by presenting a critique of the consensus frameworks of NOS in school science. I argued that these frameworks (1) lack clarity in terms of how NOS-related ideas could be applied for various ends, (2) portray a distorted image of the substantive content of NOS and the process of its development, and (3) lack a developmental trajectory for how to address NOS at different grade levels. As a solution to these problems, I suggested replacing NOS-related ideas in school science with a NOS curriculum. I envisioned a NOS curriculum that (1) addresses NOS both as an educational end and as a means for socioscientific decision making, (2) holds critical thinking as its foundational pillar, and (3) situates NOS learning across a developmental trajectory with critical thinking as a progression unit. A NOS curriculum with these characteristics is one contribution of this study. Such a curriculum is philosophically and pedagogically reasonable for several reasons, which I address in the paragraphs that follow.

One argument made in this study is that critical thinking is a practice of NOS. Critical thinking is a major mechanism that is employed in philosophical debates about NOS. Consequently, I suggested bringing it into the heart of NOS in school science. I argued that the proposed NOS curriculum with critical thinking as its foundational pillar portrays an authentic image of the substantive content of NOS and the process of its development. Moreover, as critical thinking involves discriminating between choices, some of these choices need to be brought to the discussion table in the first place. Bringing various positions on NOS and socioscientific issues into the science classroom would show respect towards diversity in scholarly work. Such a position does not tend to create a balanced or neutral position in any regard. In fact, as the primary focus is placed on critical thinking – the same mechanism employed by scholars involved in philosophical debates on NOS – and as future citizens are taught to think critically *about* NOS and critically *with* NOS in regard to several positions, the proposed NOS curriculum tends to become *philosophically reasonable*.

One contribution towards a philosophically reasonable NOS curriculum is the CT-NOS framework for addressing NOS in school science. I synthesized the CT-NOS framework based upon the theoretical ideas raised in this study. The framework is delimited by focusing on student learning, showing how students can engage in critical thinking about NOS and critical thinking with NOS. There is a need to use the same theoretical ideas in order to develop sub-frameworks that focus on teacher role, learning environment, and assessment, to name just a few. The various sub-frameworks could then be superimposed to make the overall CT-NOS framework more comprehensive. In addition, there is a need to develop a practitioners' version of the CT-NOS framework using teacher-friendly interpretations instead of academic jargon. The CT-NOS framework also needs to be further refined based on scholarly discussions, as well as on empirical evidence.

As critical thinking is brought into the heart of NOS in school science, the critical thinker is always able to make choices in determining what to believe or how to act. Consequently, whether in guiding future citizens towards thinking critically *about* NOS or critically *with* NOS, the intention is to prepare them during their school years to possess the necessary tools and to develop a mindset so that they can eventually deal effectively with competing viewpoints and make informed decisions. By focusing on *developing a mindset* I highlight the importance of developmental aspects associated with engaging in critical thinking about NOS and critical thinking with NOS. I have explored situating NOS learning across a developmental pathway thus contributing towards a *pedagogically reasonable* NOS curriculum.

It is important to clarify that a philosophically and a pedagogically reasonable NOS curriculum is not simply the sum of its parts, that is, the philosophical and the pedagogical. The present study aimed to establish a connection between the philosophical and the pedagogical by exploring a developmental trajectory for the CT-NOS framework. I argued that critical thinking rather than the substantive content of NOS needs to be placed across a developmental trajectory. Critical thinking was examined through a developmental lens in order to provide philosophical and pedagogical bases for the proposed NOS curriculum. I developed an example showing the likelihood of one of Ennis's concepts of critical thinking (causal generalizations) contributing to the creation of learning progressions. Undoubtedly, the example needs to be refined and further supported by developmental research. Moreover, future research needs to target developing learning progressions for other concepts of critical thinking. Developmental trajectories also need to be developed for skills and dispositions of critical thinking and should not be restricted to concepts of critical thinking. These progressions also need to be tested empirically with cohorts of students. Longitudinal studies need to be designed in order to better understand the progressions over the developmental years. Finally, a more detailed curriculum involving the delineation of specific learning performances and assessment tasks needs to be proposed.

The empirical study of teachers' views of a lesson prepared using the CT-NOS framework complemented some of the theoretical claims of this study and suggested paths for future work. The results showed that most participants found that the lesson was somewhat feasible for a secondary science classroom, was useful or somewhat useful to their students, and was interesting. These generally positive teacher views are encouraging. Despite the various challenges and the huge amount of work required, I suggested that the theoretical claims developed in this dissertation have the potential to be bases for a long-term research and development agenda and are worth pursuing further.

There were a number of challenges identified in the empirical study. One challenge was related to critical thinking itself. If critical thinking is to be a foundational pillar of NOS in school science, then teachers need to be at ease with it. Many teachers offered vague definitions of critical thinking and had difficulty teaching it. Moreover, in spite of the fact that none of the participating teachers in this study was negative regarding *critical thinking about NOS*, a number of them viewed controversial elements in the lesson to be problematic. Teachers need support so that they can reflect on their own understandings of critical thinking and develop strategies for effectively teaching critical thinking in their classrooms.

Another challenge was the teachers' difficulties in differentiating between critical thinking about NOS and critical thinking with NOS. I acknowledge that one workshop cannot make the participating teachers see clearly the distinction between the two. However, the study revealed a number of factors that may have impeded teachers from developing a distinction between critical thinking about NOS and critical thinking with NOS. These included defining critical thinking as a general skill or general skills that could be transferred across different situations, having alternative definitions of the term NOS, and being unable to differentiate between doing inquiry and reflecting on the inquiry process. In terms of research, further understanding of these factors and identifying strategies for dealing with them in teacher education settings is important. As critical thinking about NOS and critical thinking with NOS are indispensable in school science, there is the need to provide guidance to science teachers so that they can (1) understand the significance of both, (2) understand how the two contexts can serve as platforms upon which to develop learners' critical thinking, (3) develop their understandings of the construct of NOS, and (4) differentiate between doing inquiry and critically reflecting on the inquiry process, as well as developing strategies so that they can help their students differentiate between the two.

Despite the fact that most participants did not directly comment on developmental aspects related to the NOS lesson, all but one teacher found the lesson either feasible or somewhat feasible for inclusion in a secondary level science course. This is quite encouraging. The NOS lesson that was prepared using the CT-NOS framework along with all of the examples provided throughout this dissertation were at the secondary level. There is a need to develop NOS lessons applicable for the primary and middle school levels using the CT-NOS framework, and to get feedback from middle and elementary teachers. Moreover, the lessons need to be taken to actual classrooms and taught to students with the purpose of studying their feasibility, usefulness and interestingness, and also of understanding students' critical thinking patterns about and with NOS. Empirical studies, both cohort and longitudinal, could be designed to help us understand (a) developmental factors associated with the CT-NOS framework, (b) the processes and outcomes that result from engaging learners in critical thinking about NOS and critical thinking with NOS, (c) what factors contribute to student critical thinking about and with NOS, and (d) what kinds of guidance would optimize their learning. In terms of science teacher education, there is a need to determine optimum ways to support science teachers so that they can effectively guide their students to engage in critical thinking about NOS and critical thinking with NOS. Developing professional development programs and resources for pre-service as well as in-service science teachers is crucial as well.

The empirical study was delimited to exploring secondary science teachers' views of a lesson prepared using the CT-NOS framework. Understanding the views of stakeholders other than science teachers regarding the CT-NOS framework is equally important and needs to be addressed. Stakeholders include science education policy developers, science textbook authors, science education researchers, and curriculum designers, to name just a few. It is important to get professional feedback from a diverse audience with the purpose of improving the CT-NOS framework and developing more effective NOS lessons.

Finally, it is worth highlighting that the present study contributes *towards* developing a philosophically and a pedagogically reasonable NOS curriculum. It is an agenda that I have proposed through this work which can facilitate scholarly discussion in the field and open paths for new possibilities for empirical research. The theoretical claims need not only to be scrutinized and further refined as a result of collective effort, but also to be tested empirically. I recognize that developing the envisioned curriculum is a team effort and a long, ongoing process that could not be restricted within the boundaries of the timeline of a doctoral program.

References

Abd-El-Khalick, F. (2012a). Examining the sources for our understandings about science: Enduring conflations and critical issues in research on nature of science in science education. *International Journal of Science Education, 34,* 353-374. doi: 10.1080/09500693.2011.629013

Abd-El-Khalick, F. (2012b). Nature of science in science education: Towards a coherent framework for synergistic research and development. In B.J. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second international handbook of science education* (pp. 1041-1060). New York: Springer. doi: 10.1007/978-1-4020-9041-7_69

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of NOS. *Science Education, 88*, 785-810. doi: 10.1002/sce.10143

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*, 417-436. doi: 10.1002/(SICI)1098-237X(199807)82:4<417::AID-SCE1>3.3.CO;2-

Abd-El-Khalick, F., & Lederman, N. G. (2000a). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37,* 1057-1095. doi: 10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Abd-El-Khalick, F., & Lederman, N. G. (2000b). Improving science teachers' conceptions of nature of science: a critical review of the literature.

International Journal of Science Education, 22, 665–701. doi: 10.1080/09500690050044044

Ahlbom, A., Feychting, M., Green, A., Kheifets, L., Savitz, D. A., Swerdlow, A. J., & ICNIRP Standing Committee on Epidemiology. (2009). Epidemiologic evidence on mobile phones and tumor risk: A review. *Epidemiology, 20*, 639-652. doi: 10.1097/EDE.0b013e3181b0927d

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37,* 295-317. doi: 10.1002/(SICI)1098-2736(200004)37:4<295::AID-TEA2>3.0.CO;2-2

Akerson, V. L., Buck, G. A., Donnelly, L. A., Narguand-Joshi, V., & Weiland, I. S. (2011). The importance of teaching and learning nature of science in early childhood years. *Journal of Science Education and Technology, 20,* 537-549. doi: 10.1007/s10956-011-9312-5

Akerson, V. L., & Hanuscin, D. L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research in Science Teaching, 44*, 653-680. doi: 10.1002/tea.20159

Akerson, V., & Donnelly, L. A. (2010). Teaching nature of science to k-2 students: What understandings can they attain? *International Journal of Science Education, 32,* 97-124. doi: 10.1080/09500690902717283

Akindehin, F. (1988). Effect of an instructional package on preservice science teachers' understanding of the nature of science and acquisition of science-related attitudes. *Science Education, 72,* 73-82. doi: 10.1002/sce.3730720107

Alberta Learning. (2003). *Science grades 7-8-9.* Retrieved from http://education.alberta.ca/media/654829/sci7to9.pdf

Alters, B. J. (1997a). Nature of science: A diversity or uniformity of ideas? *Journal of Research in Science Teaching, 34,* 1105-1108. doi: 10.1002/(SICI)1098-2736(199712)34:10<1105::AID-TEA9>3.0.CO;2-V

Alters, B. J. (1997b). Whose nature of science? *Journal of Research in Science Teaching, 34,* 39-55. doi: 10.1002/(SICI)1098-2736(199701)34:1<39::AID-TEA4>3.0.CO;2-P

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy: A Project 2061 report*. Washington, D.C.: American Association for the Advancement of Science.

Arons, A. B. (1983). Achieving wider scientific literacy. *Daedalus, 112*(2), 91-122.

Bailin, S. (2002). Critical thinking and science education. *Science & Education, 11,* 361-375. doi: 10.1023/A:1016042608621

Bailin, S., Case, R., Coombs, J. R., & Daniels, L. B. (1999). Conceptualizing critical thinking. *Journal of Curriculum Studies, 31,* 285-302.

Baram-Tsabari, A., & Yarden, A. (2005). Text genre as a factor in the formation of scientific literacy. *Journal of Research in Science Teaching, 42,* 403-428. doi: 10.1002/tea.20063

Bataineh, O., & Alazzi, K. F. (2009). Perceptions of Jordanian secondary schools teachers towards critical thinking. *International Education, 38*(2), 56-72. Retrieved from http://trace.tennessee.edu/cgi/viewcontent.cgi?article=1162&context=internationaleducation

Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it! Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching, 40,* 487-509. doi: 10.1002/tea.10086

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education, 87,* 352-377. doi: 10.1002/sce.10063

Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. *Journal of Research in Science Teaching, 37,* 563-581. doi: 10.1002/1098-2736(200008)37:6<563::AID-TEA4>3.0.CO;2-N

Biesta, G. (2007). Why "what works" won't work: Evidence-based practice and the democratic deficit in educational research. *Educational Theory, 57,* 1-22. doi: 10.1111/j.1741-5446.2006.00241.x

BouJaoude, S., & Abd-El-Khalick, F. (2004). A decade of science education research in Lebanon (1992-2002): Trends and issues. In K. Mutua & C.S. Sunal (Eds.), *Research on education in Africa, the Caribbean, and the Middle East: An historic overview* (pp. 203-241) .Greenwich CT: Info Age Press.

Brewer, W. F., & Samarapungavan, A. (1991). Children's theories vs. scientific theories: Differences in reasoning or differences in knowledge?. In R. R. Hoffman & D. S. Palermo (Eds.), *Cognition and the symbolic processes: Applied and ecological perspectives* (pp. 209-232). NJ: Laurence Erlbaum.

Brickhouse, N. W., Dagher, Z. R., Shipman, H. L., & Letts IV, W. J. (2002). Evidence and warrants for belief in a college astronomy course. *Science & Education, 11,* 573-588. doi: 10.1023/A:1019693819079

Brill, G., & Yarden, A. (2003). Learning biology through research papers: A stimulus for question-asking by high-school students. *Cell Biology Education, 2,* 266-274. doi: 10.1187/cbe.02-12-0062

Bulte, A. M. W., Westbroek, H. B., de Jong, O., & Pilot, A. (2006). A research approach to designing chemistry education using authentic practices as contexts. *International Journal of Science Education, 28,* 1063-1086. doi: 10.1080/09500690600702520

Bybee, R., & DeBoer, G. E. (1994). Research on goals for the science curriculum. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 357-387). New York: Macmillan.

Bybee, R., McCrae, B., & Laurie, R. (2009). PISA 206: An assessment of scientific literacy. *Journal of Research in Science Teaching, 46,* 865-883. doi: 10.1002/tea.20333

Callahan, B. E. (2009). *Enhancing nature of science understanding, reflective judgment, and argumentation through socioscientific issues* (Doctoral dissertation). Retrieved from http://scholarcommons.usf.edu/etd/1886/

Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, *28*, 235-251.

Catley, K., Lehrer, R., & Reiser, B. (2005). *Tracing a prospective learning progression for developing understanding of evolution*. Commissioned paper for the National Research Council Committee on Test Design for K-12 Science Achievement. Washington, DC. Available: http://www7.nationalacademies.org/bota/Evolution.pdf

Cobern, W. W. & Loving, C. C. (2001). Defining “science” in a multicultural world: Implications for science education. *Science Education, 85,* 50-67. doi: 10.1002/1098-237X(200101)85:1<50::AID-SCE5>3.0.CO;2-G

Cohen, L. B., & Oakes, L. M. (1993). How infants perceive a simple causal event. *Developmental Psychology, 29*(4), 421-433.

Corcoran, T., Mosher, F. A., & Rogat, A. (2009). *Learning progressions in science: An evidence-based approach to reform* (Research Report No. RR-63). Consortium for Policy Research in Education. Retrieved from http://www.cpre.org/images/stories/cpre_pdfs/lp_science_rr63.pdf

Council of Ministers of Education, Canada (CMEC). (1997). Common Framework of Science Learning Outcomes: Pan-Canadian Protocol for Collaboration on School Curriculum (Toronto: Council of Ministers of Education, Canada). Accessed online at http://publications.cmec.ca/science/framework/

Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the control of variables strategy. *Child Development, 70,* 1098-1120. doi: 10.1111/1467-8624.00081

Dagher, Z. R., & BouJaoude, S. (2005). Students' perceptions of the nature of evolutionary theory. *Science Education, 89,* 378-391. doi: 10.1002/sce.20054

De Boer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37,* 582-601.

Doddington, C. (2007). Critical thinking as a source of respect for persons: A critique. *Educational Philosophy and Theory [Special Edition], 39,* 449-459. doi: 10.1111/j.1469-5812.2007.00350.x

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23,* 5-12. doi: 10.3102/0013189X023007005

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young People's Images of Science*. Philadelphia: Open University Press.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. Committee on Science Learning, National Research Council. Washington, DC: National Academies Press.

Dutt-Doner, K. M., Cook-Cottone, C., & Allen, S. (2007). Improving classroom instruction: Understanding the developmental nature of analyzing primary sources. *Research in Middle Level Education RMILE Online, 30*(6), 1-20.

Eisenhart, M., Finkel, E., & Marion, S. F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal, 33,* 261-295.

Ennis, R. H. (1964). A definition of critical thinking. *The Reading Teacher, 17,* 599-612.

Ennis, R. H. (1969). *Logic in Teaching.* NJ: Prentice Hall.

Ennis, R. H. (1989). Critical thinking and subject specificity: Clarification and needed research. *Educational Researcher, 18,* 4-10. doi: 10.3102/0013189X018003004

Ennis, R. H. (1990). The extent to which critical thinking is subject specific: Further clarification. *Educational Researcher, 19,* 13-16. doi: 10.3102/0013189X019004013

Ennis, R. H. (1996a). *Critical Thinking.* NJ: Prentice Hall.

Ennis, R.H. (1996b). Critical thinking dispositions: Their nature and assessability. *Informal Logic, 18,* 165-182.

European Commission (1995). Teaching and learning: Towards the learning society. White paper on education and training [COM (95) 590]. Brussels: European Commission.

Falk, H., Brill, G., & Yarden, A. (2005). Scaffolding learning through research articles by a multimedia curriculum guide. In M. Ergazaki, J. Lewis, & V. Zogza (Eds.), *Proceedings of The 5th Conference of The European Researchers in Didactics of Biology (ERIDOB)* (pp. 175–192). Patras, Greece.

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education, 30,* 1841-1866. doi: 10.1080/09500690701579553

Geelan, D. R. (1997). Epistemological anarchy and the many forms of constructivism. *Science & Education, 6,* 15-28. doi: 10.1023/A:1017991331853

Gess-Newsome, J. (2002). The use and impact of explicit instruction about the NOS and science inquiry in an elementary science methods course. *Science & Education, 11,* 55-67. doi: 10.1023/A:1013054823482

Giere, R. N. (1988). *Explaining science: A cognitive approach*. Chicago, IL: University of Chicago Press.

Gott, R., & Duggan, S. (1998). Understanding scientific evidence – Why it matters and how it can be taught. In M. Ratcliffe (Ed.), *ASE secondary science education* (pp. 92-99). Hatfield: ASE.

Gott, R., Duggan, S., Roberts, R., & Hussain, A. (2002). *Concepts of evidence: The thinking behind the doing (GCSE version)*. Retrieved from http://www.dur.ac.uk/richard.gott/Evidence/cofev.htm

Grandy, R. E. (1998). Constructivisms and objectivity: Disentangling metaphysics from pedagogy. In M. Matthews (Ed.), *Constructivism in science education* (pp 113-123). Dordrecht: Kluwer.

Hand, M., & Levinson, R. (2011). Discussing controversial issues in the classroom. *Educational Philosophy and Theory.* doi: 10.1111/j.1469-5812.2010.00732.x

Harré, R. (1986). *Varieties of realism*. Oxford: Blackwell.

Harris, P. (2002). What do children learn from testimony? In P. Carruthers, S. Stich, and M. Siegal (Eds.), *The cognitive basis of science* (pp. 316-334). NY: Cambridge University Press.

Hickling, A. K., &Wellman, H. M. (2001). The emergence of children's causal explanations and theories: Evidence from everyday conversation. *Developmental Psychology, 37,* 668-683. doi: 10.1037//0012-1649.37.5.668

Hill, V., & Pillow, B. H. (2006). Children's understanding of reputations. *The Journal of Genetic Psychology, 167,* 137-157. doi: 10.3200/GNTP.167.2.137-157

Hodson, D. (1993). Philosophic stance of secondary school science teachers, curriculum experiences, and children's understanding of science: some preliminary findings. *Interchange, 24*, 41-52.

Holman, J. (1997). The national curriculum: A golden opportunity for scientific literacy. In W. Graber & C. Bolte (Eds.), *Scientific literary: An international symposium* (pp. 275-285). Kiel, Germany, Institut fur die Padagogik der Naturwissebschaften.

Hsu, P., van Eijck, M., & Roth, W. (2010). Students' representations of scientific practice during a science internship: Reflections from an activity-theoretic perspective. *International Journal of Science Education, 32,* 1243-1266. doi: 10.1080/09500690903029563

Hurd, P. D. (1998). Scientific literacy: New mind for a changing world. *Science Education, 82,* 407-416. doi: 10.1002/(SICI)1098-237X(199806)82:3<407::AID-SCE6>3.0.CO;2-G

Irzik, G. & Irzik, S. (2002). Which multiculturalism? *Science & Education, 11,* 393-403. doi: 10.1023/A:1016060516735

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education, 20,* 591-607. doi: 10.1007/s11191-010-9293-4

Jiménez-Aleixandre, M. P. (2008). Designing argumentation learning environments. In S. Erduran & M. P. Jiménez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research*. Dordrecht: Springer. doi: 10.1007/978-1-4020-6670-2

Jiménez-Aleixandre, M. P., & Erduran, S. (2008). Argumentation in science education: An overview. In S. Erduran & M. P. Jiménez-Aleixandre (Eds), *Argumentation in science education: Perspectives from classroom-based research*. Dordrecht: Springer. doi: 10.1007/978-1-4020-6670-2

Keating, D. P. (1988). *Adolescents' ability to engage in critical thinking.* [S.l.]: Distributed by ERIC Clearinghouse.

Khishfe, R. (2008). The development of seventh graders' views of nature of science. *Journal of Research in Science Teaching, 45*, 470-496. doi: 10.1002/tea.20230

Khishfe, R. (2012). Nature of science and decision-making. *International Journal of Science Education, 34,* 67-100. doi: 10.1080/09500693.2011.559490

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*, 551-578. doi: 10.1002/tea.10036

Khurana, V. G., Teo, C., Kundi, M., Hardell, L., & Carlberg, M. (2009). Cell phones and brain tumors: A review including the long-term epidemiologic data. *Surgical Neurology, 72,* 205-215. doi: 10.1016/j.surneu.2009.01.019

Kim, S. Y., & Irving, K. E. (2010). History of science as an instructional context: Student learning in genetics and nature of science. *Science & Education, 19,* 187-215. doi: 10.1007/s11191-009-9191-9

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults.* San Francisco: Jossey-Bass.

King, P. M., & Kitchener, K. S. (2004). Reflective judgment: Theory and research on the development of epistemic assumptions through adulthood. *Educational Psychologist, 39,* 5-18. doi: 10.1207/s15326985ep3901_2

Klahr, D., Fay, A. L., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology*, *25*(1), 111-146.

Kolstø, S. D. (2001a). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85,* 291-310. doi: 10.1002/sce.1011

Kolstø, S. D. (2001b). ‘To trust or not to trust,… ‘ -pupils’ ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education, 23,* 877-901. doi: 10.1080/09500690010016102

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7,* 313-350. Doi: 10.1207/s15327809jls0703&4_3

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

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28,* 16-25+46. doi: 10.3102/0013189X028002016

Kuhn, D., & Pearsall, S. (2000). Developmental origins of scientific thinking. *Journal of Cognition and Development, 1,* 113-129. doi: 10.1207/S15327647JCD0101N_11

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84,* 71-94. doi: 10.1002/(SICI)1098-237X(200001)84:1<71::AID-SCE6>3.0.CO;2-C

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29,* 331-359. doi: 10.1002/tea.3660290404

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36,* 916-929. doi: 10.1002/(SICI)1098-2736(199910)36:8<916::AID-TEA2>3.0.CO;2-A

Lederman, N. G. (2004). Syntax of nature of science within inquiry and science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp. 301-317). Dordrecht: Kluwer.

Leslie, A. M. (1984). Spatiotemporal continuity and the perception of causality in infants. *Perception, 13,* 287-305. doi: 10.1068/p130287

Leslie, A. M., & Keeble, S. (1987). Do six-month-olds perceive causality? *Cognition, 25,* 265-288. Retrieved from http://www2.psych.ubc.ca/~hhyeung/psyc412/LeslieKeeble.pdf

Lipman, M. (1988). Critical thinking – What can it be?. *Educational Leadership, 46,* 38-43. Retrieved from http://www.ascd.org/ASCD/pdf/journals/ed_lead/el_198809_lipman.pdf

Lipman, M. (2003). *Thinking in education.* 2nd Ed., Cambridge: Cambridge University Press.

Liu, S, Y., Lin, C. S., & Tsai, C. C. (2011). College students' scientific epistemological views and thinking patterns in socioscientific decision making. *Science Education, 95,* 497-517. doi: 10.1002/sce.20422

Loving, C. C. (1997). From the summit of truth to its slippery slopes: Science education's journey through positivist-postmodern territory. *American Educational Research Journal, 34,* 421-452. doi: 10.2307/1163245

Makar, K., & McPhee, D. (2009). Young children's explorations of average in an inquiry classroom. In R. Hunter, B. Bicknell, & T. Burgess (Eds.), *Crossing Divides: Proceedings of the 32nd Annual Conference of the*

Mathematics Education Research Group of Australasia (Vol. 1) (pp. 347-354). Palmerston North, NZ: MERGA.

Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science.* NY: Routledge.

Matthews, M. R. (1998). In defense of modest goals when teaching about the nature of science. *Journal of Research in Science Teaching, 35,* 161-174. doi: 10.1002/(SICI)1098-2736(199802)35:2<161::AID-TEA6>3.0.CO;2-Q

McComas, W. F., AlMazroa, H., & Clough, M. P. (1998). The nature of science in science education: An introduction. *Science & Education, 7,* 511-532. doi: 10.1023/A:1008642510402

McDonald, C. V. (2010). The influence of explicit nature of science and argumentation instruction on preservice primary teachers' views of nature of science. *Journal of Research in Science Teaching, 47,* 1137-1164. doi: 10.1002/tea.20377

McPeck, J. E. (1981). *Critical thinking and education*. Oxford: Martin Robertson.

McPeck, J. E. (1990). Critical thinking and subject specificity: A reply to Ennis. *Educational Researcher, 19,* 10-12. doi: 10.3102/0013189X019004010

Melzer, A. M., Weinberger, J., Zinman, M. R. (1998). *Multiculturalism and American democracy*. Lawrence: University Press of Kansas.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook (Second edition).* California: SAGE.

Millar, R. (1996). Towards a science curriculum for public understanding. *School Science Review, 77*(280), 7–18.

Minner, D. D., Jurist Levy, A., & Century, J. (2010). Inquiry-based science instruction – What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47,* 474-496. doi: 10.1002/tea.20347

Mokros, J., & Russell, S. J. (1995). Children's concepts of average and representativeness. *Journal for Research in Mathematics Education, 26,* 20-39. doi: 10.2307/749226

Muentener, P., & Lakusta, L. (2011). The intention-to-cause bias: Evidence from children's causal language. *Cognition, 119,* 341-355. doi: 10.1016/j.cognition.2011.01.017

National Council of Teachers of Mathematics [NCTM] (2000). *Principles and standards for school mathematics.* Reston, VA. Retrieved from http://www.nctm.org/standards/content.aspx?id=16909

National Research Council [NRC] (1996). *National science education standards*. Washington, DC: National Academic Press. Retrieved from http://www.nap.edu/openbook.php?record_id=4962

National Research Council [NRC]. (2012). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13165

National Science Teachers' Association [NSTA]. (2012). *NSTA feedback to Achieve on next generation science standards first public draft: June 2012.* Retrieved from http://www.nsta.org/about/standardsupdate/feedback.aspx

Nistor, N., Dehne, A., & Drews, F. T. (2010). Mass customization of teaching and training in organizations: design principles and prototype evaluation. *Studies in Continuing Education, 32,* 251-267. doi: 10.1080/0158037X.2010.517996

Next Generation Science Standards for Today's Students and Tomorrow's Workforce [NGSS]. (2012a). *Next generation science standards (first public draft).* Retrieved from http://www.nextgenscience.org/next-generation-science-standards

Next Generation Science Standards for Today's Students and Tomorrow's Workforce [NGSS]. (2012b). *The nature of science in the next generation science standards (May 2012 draft).* Retrieved from http://www.nextgenscience.org/sites/ngss/files/Nature%20of%20Science%20for%20Public%20Release%20FINAL%20PUBLIC%20May%20Draft_0.pdf

Nicoll, B. (1996). *Developing minds: Critical thinking in k-3.* Paper presented at the California Kindergarten Conference, San Francisco, CA. Distributed by ERIC Clearinghouse.

Nola, R., & Irzik, G. (2011). A family resemblance approach. In N. G. Lederman, R. Nola, & G. Irzik, *Current philosophical and educational issues in nature of science (NOS) research, and possible future directions*. Plenary session conducted at the 11th International IHPST and 6th Greek History, Philosophy and

Science Teaching Joint Conference, Thessaloniki, Greece. Abstract retrieved from http://ihpst2011.eled.auth.gr/ihpst2011_book_of_abstracts

Norris, S. P. (1984). Defining observational competence. *Science Education, 68,* 129-142. doi: 10.1002/sce.3730680206

Norris, S. P. (1985). Synthesis of research on critical thinking. *Educational Leadership, 42*(8), 40-45.

Norris, S. P., & Korpan, C. A. (2000). Science, views about science, and pluralistic science education. In R. Millar, J. Leach & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 227-244). Buckingham: Open University Press.

Norris, S. P., Macnab, J. S., Wonham, M., & De Vries, G. (2009). West Nile virus: Using adapted primary literature in mathematical biology to teach scientific and mathematical reasoning in high school. *Research in Science Education, 39,* 321-329. doi: 10.1007/s11165-008-9112-y

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87,* 224-240. doi: 10.1002/sce.10066

Norris, S. P., Stelnicki, N., & De Vries, G. (2011). Teaching mathematical biology in high school using adapted primary literature. *Research in Science Education.* Advance online publication. doi: 10.1007/s11165-011-9215-8

Oakes, L. M., & Cohen L. B. (1990). Infant perception of a causal event. *Cognitive Development, 5,* 193-207. doi: 10.1016/0885-2014(90)90026-P

Oancea, A. & Pring, R. (2008). The importance of being thorough: On systematic accumulations of 'what works' in education research. *Journal of Philosophy of Education, 42,* 15-39. doi: 10.1111/j.1467-9752.2008.00633.x

Organization for Economic Co-operation and Development (OECD). (2003). *The PISA 2003 assessment framework: Mathematics, reading, science and problem solving knowledge and skills*, OECD. Retrieved from http://www.oecd.org/document/29/0,3746,en_32252351_32236173_33694301_1_1_1_1,00.html

Organization for Economic Co-operation and Development (OECD). (2006). *Assessing scientific, reading and mathematical literacy: A framework for PISA 2006.* Paris: OECD.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40,* 692-720. doi: 10.1002/tea.10105

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41,* 994-1020. doi: 10.1002/tea.20035

Paraskevopoulou, E., & Koliopoulos, D. (2011). Teaching the nature of science through the Millikan-Ehrenhaft dispute. *Science & Education, 20,* 943-960. doi: 10.1007/s11191-010-9308-1

Paul, R. W. (1994). Teaching critical thinking in the strong sense: A focus on self-deception, world views, and a dialectical mode of analysis. In K. S.

Walters (Ed.), *Re-Thinking reason: New perspectives in critical thinking* (pp. 181-198). New York: SUNY.

Paul, R. W., Elder, L., & Bartell, T. (1997). *Teachers of teachers: Examining preparation for critical thinking*. Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL. Retrieved from http://www.eric.ed.gov/PDFS/ED410276.pdf

Peters, M. A. (2007). Kinds of thinking, styles of reasoning. *Educational Philosophy and Theory, special edition: Critical Thinking and Learning, 39,* 350-363. doi: 10.1111/j.1469-5812.2007.00344.x

Phillips, D. C. (1995). The good, the bad, and the ugly: The many faces of constructivism. *Educational Researcher*, *24*, 5-12. doi: 10.3102/0013189X024007005

Phillips, D. C., & Burbules, N. C. (2000). *Postpositivism and educational research.* Lanham: Rowman & Littlefield.

Prasad, P. (2005). *Crafting qualitative research: Working in the postpositivist traditions.* NY: Sharpe.

Roth, W. M. (1995). *Authentic school science: knowing and learning in open-inquiry science laboratories*. Dordrecht: Kluwer.

Rudolph, J. L. (2000). Reconsidering the 'nature of science' as a curriculum component. *Journal of Curriculum Studies, 32*, 403–419. doi: 10.1080/002202700182628

Russell, S. J., & Mokros, J. (1990). What's typical? Children's and teachers' ideas about average. In D. Vere-Jones (Ed.), *Proceedings of the Third*

International Conference on Teaching Statistics (pp. 307-313). Vooburg, Netherlands: International Statistical Institute.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate students' images of science. *Journal of Research in Science Teaching, 36,* 201-219. doi: 10.1002/(SICI)1098-2736(199902)36:2<201::AID-TEA6>3.0.CO;2-H

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education, 26,* 387–409. doi: 10.1080/0950069032000119456

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching, 42,* 112–138. doi: 10.1002/tea.20042

Schiro, M. S. (2008). *Curriculum theory: Conflicting visions and enduring concerns.* CA: Sage.

Schommer-Aikins, M., & Hutter, R. (2002). Epistemological beliefs and thinking about everyday controversial issues. *Journal of Psychology, 136*(1), 5 - 20.

Schwab, J. J. (1962). The teaching of science as enquiry. In J. Schwab & P. Brandwein (Eds.), *The teaching of science*. Cambridge, MA: Harvard University Press.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88,* 610-645. doi: 10.1002/sce.10128

Shymansky, J. A., Hedges, L. V., & Woodworth, G. (1990). A reassessment of the effects of inquiry-based science curricula of the 60's on student performance. *Journal of Research in Science Teaching, 27,* 127-144. doi: 10.1002/tea.3660270205

Siegel, H. (1980). *Critical thinking as an educational ideal.* Paper presented at the annual meeting of the American Educational Research Association, Boston, MA. Retrieved from http://www.eric.ed.gov/PDFS/ED187762.pdf

Siegel, H. (1988). *Educating reason: rationality, critical thinking, and education.* New York: Routledge.

Siegel, H. (1997). Science education: Multicultural and universal. *Interchange, 28,* 97-108. doi: 10.1023/A:1007314420384

Siegel, H. (2007). Multiculturalism and rationality. *Theory and Research in Education, 5,* 203-223. doi: 10.1177/1477878507077735

Slavin, R. E. (2008). Perspectives on evidence-based research in education – what works? Issues in synthesizing educational program evaluations. *Educational Researcher, 37,* 5-14. doi: 10.3102/0013189X08314117

Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F., & Clough, M. P. (1997). How great is the disagreement about the nature of science: A response to Alters. *Journal of Research in Science Teaching, 34,* 1101-1103. doi: 10.1002/(SICI)1098-2736(199712)34:10<1101::AID-TEA8>3.0.CO;2-V

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications for research on children's learning for standards and assessment: A proposed learning progression for matter and atomic-molecular theory. *Measurement, 14,* 1-98. doi: 10.1207/s15366359mea0401&2_1

Smith, C., Wiser, M., Anderson, C. A., Krajick, J., and Coppola, B. (2004). *Implications of research on children's learning for assessment: Matter and atomic molecular theory*. Commissioned paper for the National Research Council Committee on Test Design for K-12 Science Achievement, Washington, DC. Retrieved from http://www7.nationalacademies.org/bota/Big%20Idea%20Team_%20AMT.pdf

Snively, G. & Corsiglia, J. (2001). Discovering indigenous science: Implications for science education. *Science Education, 85,* 6-34. doi: 10.1002/1098-237X(200101)85:1<6::AID-SCE3>3.0.CO;2-R

Solomon, J., Scott, L., & Duveen, J. (1996). Large-scale exploration of pupils' understanding of the nature of science. *Science Education, 80,* 493-508. doi: 10.1002/(SICI)1098-237X(199609)80:5<493::AID-SCE1>3.0.CO;2-6

Stanley, W. B., & Brickhouse, N. W. (2001). Teaching sciences: The multicultural question revisited. *Science Education, 85,* 35-49. doi: 10.1002/1098-237X(200101)85:1<35::AID-SCE4>3.0.CO;2-6

Staver, J. R. (1998). Constructivism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching, 35,* 501-520. doi: 10.1002/(SICI)1098-2736(199805)35:5<501::AID-TEA3>3.0.CO;2-T

Strand-Cary, M., & Klahr, D. (2008). Developing elementary science skills: Instructional effectiveness and path independence. *Cognitive Development, 23,* 488-511. doi: 10.1016/j.cogdev.2008.09.005

Tamir, P. (1983). Inquiry and the science teacher. *Science Education, 67,* 657-672. doi: 10.1002/sce.3730670513

Taylor, C. (1994). The politics of recognition. In A. Gutmann (Ed.), *Multiculturalism* (pp. 25-73). Princeton: Princeton University Press.

Taylor, J. L., & Swinbank, E. (2007). Designing a course that promotes debate: the perspectives on science (POS) AS level model. *School Science Review, 88*(324), 41-48.

Taylor, J. L., & Swinbank, E. (2011). Perspectives on science: A qualification in the history, philosophy and ethics of science for 16 – 19 year old students. In F. Seroglou, V. Koulountzos, & A. Siatras (Eds.), *Science & Culture: Promise, Challenge and Demand* (pp. 730-734). Thessaloniki: Epikentro.

Tenopir, C., & King, D. W. (2004). *Communication patterns of engineers.* Hobolary NY: Wiley.

Toth, E. E., Klahr, D., & Chen, Z. (2000). Bridging research and practice: A cognitively based classroom intervention for teaching experimentation skills to elementary school children. *Cognition and Instruction, 18,* 423-459. doi: 10.1207/S1532690XCI1804_1

Van den Akker, J. (1998). The science curriculum: Between ideals and outcomes. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education (Vol. I).* London: Kluwer.

Van den Akker, J. (2003). Curriculum perspectives: An introduction. In J. Van den Akker, W. Kuiper, & U. Hameyer (Eds.), *Curriculum landscapes and trends.* London: Kluwer.

Van den Akker, J., Fasoglio, D., & Mulder, H. (2010). *A curriculum perspective for plurilingual education.* Guide for the Development and Implementation of Curricula for Plurilingual and Intercultural Education: Council of Europe. Retrieved from http://www.coe.int/t/dg4/linguistic/Source/Source2010_ForumGeneva/SLO_persp2010_EN.pdf

Van den Broek, P. (1989). Causal reasoning and inference making in judging the importance of story statements. *Child Development, 60*(2), 286-297.

Walker, D. F. (2003). *Fundamentals of curriculum: Passion and professionalism.* NJ: Lawrence Erlbaum Associates.

Walker, K. A., & Zeidler, D. L. (2007). Promoting discourse about socioscientific issues through scaffolded inquiry. *International Journal of Science Education, 29,* 1387-1410. doi: 10.1080/09500690601068095

Wandersee, J., Mintzes, J., & Novak, J. (1994). Research on alternative conceptions in science. In D. Gable (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). NY: McMillan Publishing Company.

Watson, J. M., & Moritz, J. B. (2000a). Developing concepts of sampling. *Journal for Research in Mathematics Education, 31,* 44-70. doi: 10.2307/749819

Watson, J. M., & Moritz, J. B. (2000b). The longitudinal development of understanding of average. *Mathematical Thinking and Learning, 2,* 11-50. doi: 10.1207/S15327833MTL0202_2

Yacoubian, H. A., & BouJaoude, S. (2010). The effect of reflective discussions following inquiry-based laboratory activities on students' views of nature of science. *Journal of Research in Science Teaching*, *47*, 1229-1252. doi: 10.1002/tea.20380

Yarden, A., Brill, G., & Falk, H. (2001). Primary literature as a basis for a high-school biology curriculum. *Journal of Biological Education*, *35*(4), 190–195.

Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Teacher Education, 21,* 49-58. doi: 10.1007/BF03173684

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86,* 343-367. doi: 10.1002/sce.10025

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39,* 35-62. doi: 10.1002/tea.10008

Appendix A

Ennis's Concepts of Critical Thinking

Argument Analysis: Identifying Conclusions and Reasons

The Credibility of Sources

Observation

Deduction: Class Logic

Deduction: Propositional Logic

Experimentation, Diagnosis, and Troubleshooting

Best Explanation and Causal Inference

Generalization

Making Value Judgments

Definitions

Reference: Ennis, R.H. (1996). *Critical Thinking.* Prentice Hall: NJ.

Appendix B

Guiding Students to Read Critically and Analyze Arguments

Guide students to

a. Identify the issue

b. Identify the reasons provided

c. Identify the conclusions made

d. Evaluate whether the reasons are sufficient to establish the conclusion(s)

e. Research the broader context

f. Research the background

g. Aim for clarity

Reference: Ennis, R.H. (1996). *Critical Thinking.* Prentice Hall: NJ.

Appendix C

Criteria for Identifying Conclusions

1. Usually the conclusion somehow contributes to the author's goals, the more directly the better.
2. A proposition that is the conclusion is probably supported by one or more others.
3. Generally a conclusion of a passage should use most or all of the passage for its support.

Cues Helpful in Identifying Conclusions

- The author's calling it a conclusion
- Use of certain words (therefore, hence, thus, so)
- *Since* and *because* indicate that a reason comes next, meaning that the other part of the sentence is the conclusion
- Use of conclusion-suggesting emphasis terms such as *must* and *should*
- Often a conclusion serves as a reason for another conclusion (intermediate conclusion)
- Sometimes the "therefore" test may be helpful in determining the conclusion when there are no clear conclusion indicators

Reference: Ennis, R.H. (1996). *Critical Thinking.* Prentice Hall: NJ.

Appendix D

Causal Generalizations

A singular causal statement is about one sequence and is in the past tense: One particular thing (or set of things) caused another particular thing (or set of things). Example, "The stabbing caused Al's death". On the other hand, the statement, "Stabbing causes people to die" is a causal generalization. It is about an unlimited number of sequences. Other examples of causal generalizations are the following: "Smoking causes cancer", "Drinking causes accidents" etc.

1. Vagueness
Causal generalizations have a usually unstated and inevitably somewhat vague standard-condition qualifier that depends on the situation, and also often have a vagueness (about their degree of universality) that can be clarified to some extent and that also depends on the situation. For example, is smoking alleged to cause cancer occasionally, sometimes, often, usually, or always? The generalization does not say.

2. Causing, or Bringing About
Causation is not necessarily mechanical. Does X *cause* Y or *bring about* Y?

What Sort of Evidence can Support a General Causal Hypothesis?

A number of types of evidence can support a general causal hypothesis, but often no single type is conclusive.

(1) The existence of a singular causal instance of the generalization

(2) The representativeness of the instance

(3) The existence of a set of instances in which cases of the supported cause are associated with cases of the supported effect.
An important feature of repeated association, if it is to be evidence, is that a cause must precede (or be concurrent with) its effect. A cause cannot occur after its effect.

(4) The investigator's having deliberately introduced the independent variable

(5) The plausibility of the causal chain

(6) The derivability of the causal generalization from a set of one or more broader causal generalizations or laws

(7) The assertion of the causal generalization by a credible source

Reference: Ennis, R.H. (1996). *Critical Thinking.* Prentice Hall: NJ.

Appendix E

Criteria for Credibility of Sources

1. Background experience and knowledge
2. Lack of apparent conflict of interest
3. Agreement with others equally qualified
4. Reputation
5. Established procedures
6. Known risk to reputation
7. Ability to give reasons
8. Careful habits

Reference: Ennis, R.H. (1996). *Critical Thinking.* Prentice Hall: NJ.

Appendix F

To:
Date:

LETTER OF INITIAL CONTACT

Study Title: Experienced Science Teachers' Views of a Lesson Prepared Using the Ct-NOS Framework

Research Investigator
(contact info)

Supervisor
(contact info)

Dear ___________ ,

I would like to invite experienced secondary science teachers at (the school) to participate in a research project that I am conducting, entitled "Experienced Science Teachers' Views of a Lesson Prepared Using the Ct-NOS Framework". Experienced science teachers according to this study are defined as secondary science teachers who have a minimum of 5 years of science teaching experience in a secondary school, holding at least a bachelors degree in any science field as well as a teaching diploma or an equivalent teaching certificate. Teachers with a minimum of 15 years of science teaching experience at the secondary level do not necessarily have to hold a teaching diploma or an equivalent teaching certificate. I would appreciate if you could help me identify the experienced science teachers at your schools and place me in contact with them so that I could send each of them an information letter and a consent form.

The purpose of the research study is to evaluate experienced science teachers' views of a nature of science (NOS) lesson that is based on a new framework of school NOS (referred to as Ct-NOS) that I had been developing over the past four years. The pedagogical aim of Ct-NOS resides in promoting learners' understandings of NOS and advancing their abilities of making good decisions on science-based social issues. Ct-NOS has the potential for (1) creating new paths of research among science education scholars, (2) acting as a foundation for curriculum designers as they develop science curricula, and (3) acting as a resource for science teachers to develop NOS lessons. The results of the present study will be used in support of my doctoral dissertation. The results would also be presented at international academic conferences and would appear in scholarly publications.

I would like to conduct a 4-hour-professional development workshop for the secondary science teachers of your schools in December 2011 or January 2012 – on a day convenient to the teachers and myself. The workshop would be targeted to all secondary science teachers at your schools who might be interested in attending, including the teachers who have agreed to participate in the research study and the teachers who do not meet the recruitment criteria for this study. The purpose of the workshop is to introduce the teachers to the NOS lessons that are prepared using the Ct-NOS framework. During the workshop I would ask the teachers to play the role of students and engage in NOS-related learning activities. Next, I would guide the audience to reflect on the activities with the purpose of identifying the characteristics of the NOS lesson and ultimately the Ct-NOS framework. Finally, I would ask them to develop mock lessons based on what they have learned.

After the workshop is completed, only the teachers who I have invited to participate in the research project and who have agreed to be part of the study will be asked to fill a questionnaire. The questionnaire has a list of open-ended questions about how feasible, useful and interesting the teachers found the lesson introduced to them during the workshop. The completion of the questionnaire would need about 30 minutes and the teachers would have to make sure that they turn in the questionnaire to me right away and before they leave. During the following week I will contact them and arrange meeting time for follow up interviews. Every participant will be interviewed for about 30 minutes and the interviews would be audio recorded. I would ask them questions related to the responses that they had provided on the questionnaires.

The teachers participating in the study will be expected to participate in the workshop actively, as well as fill in the questionnaire and answer to the interview questions to the best that they could. Participating in this research project would not cost the teachers or the schools anything. The workshop would be a free professional development opportunity for the science teachers and they may use any resource that I provide them at the workshop in their science classrooms. There are no potential risks for being involved in this research project. I hope that the information that I get from this study would help me revise my NOS lesson as well as the Ct-NOS framework.

The teachers are under no obligation to participate in this study. The participation is completely voluntary. The participants are also not obliged to answer any specific questions even if participating in the study. Any participant may opt out without penalty and may ask any collected data to be withdrawn from the data base and not included in the study. The latest that one could withdraw from the study is within 3 days after being interviewed. He/she has to advise me in writing that he/she wishes to opt out, also advise in writing if he/she wishes part or all collected data to that point to be withdrawn. In that case I ensure that I would discard the data collected from him/her. The questionnaire filled out would be shredded and the audio record would be deleted.

I also ensure you that all data collected from the participants will be used only for academic purposes. The results would appear in the research investigator's doctoral dissertation, as well as in scholarly publications, academic conferences, etc. I will remove all identifying information from the data right after data collection is complete and will use a code system instead. Hence, teachers' names, school name and contact information will remain anonymous. All data will be kept confidential at all stages of this research and my supervisors and I would be the only people having access to them. Data from the questionnaires will be scanned and together with the audio records would be stored electronically in password protected files. After the completion of the research project, all data would be stored for 5 years in a password protected flash memory stored in a locked cabinet. After 5 years all data would be destroyed in a way that ensures privacy and confidentiality. You may advise me to receive a copy of the report of the research findings by sending me an email and I would be happy to share with you a copy of the report when it is ready. I may use the data I get from this study in future research, but if I do this it will have to be approved by a Research Ethics Board.

If you have any further questions regarding this study, please do not hesitate to contact either me or my supervisor. Our contact information appears at the start of this letter. The plan for this study has been reviewed for its adherence to ethical guidelines and approved by Research Ethics Board 1 (REB1) at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the REB1 Chair at (phone number). This office has no affiliation with the study investigators.

Thank you for your cooperation.

Best regards,

Hagop A. Yacoubian
Ph.D. Candidate

Appendix G

INFORMATION LETTER AND CONSENT FORM

Study Title: Experienced Science Teachers' Views of Lessons Prepared Using the Ct-NOS Framework

Research Investigator
(contact info)

Supervisor
(contact info)

Date

Dear teacher,

I would like to invite you to participate in a research project that I am conducting, entitled "Experienced Science Teachers' Views of a Lesson Prepared Using the Ct-NOS Framework". You are being invited to be in this study because you meet the recruitment criteria of this research. Experienced science teachers according to this study are defined as secondary science teachers who have a minimum of 5 years of science teaching experience in a secondary school (grades 10, 11, 12), holding at least a bachelors degree in any science field as well as a teaching diploma or an equivalent teaching certificate. Teachers with a minimum of 15 years of science teaching experience at the secondary level do not necessarily have to hold a teaching diploma or an equivalent teaching certificate. The results of this study will be used in support of my doctoral dissertation. The results would also be presented at international academic conferences and would appear in scholarly publications.

The purpose of the research study is to evaluate experienced science teachers' views of a nature of science (NOS) lesson that is based on a new framework of school NOS (referred to as Ct-NOS) that I had been developing over the past four years. The pedagogical aim of Ct-NOS resides in promoting learners' understandings of NOS and advancing their abilities of making good decisions on science-based social issues. Ct-NOS has the potential for (1) creating new paths of research among science education scholars, (2) acting as a foundation for curriculum designers as they develop science curricula, and (3) acting as a resource for science teachers to develop NOS lessons.

I will conduct a 4-hour workshop in (date) for the science teachers at your school. The purpose of the workshop is to introduce you to the NOS lesson that I have prepared using the Ct-NOS framework. During the workshop I would ask the teachers to play the role of students and engage in NOS-related learning activities. Next, I would guide the audience to reflect on the activities with the purpose of identifying the characteristics of the NOS lesson and ultimately the Ct-NOS framework. Finally, I would ask you and the other teachers to develop mock lessons based on what you have learned. The workshop will be targeted to all secondary science teachers at your school who might be interested in attending.

After the workshop is completed, only the teachers who I have recruited to participate in the research project and who have agreed to be part of the study will be asked to fill a questionnaire. If you agree to participate in this study, you would be one of the teachers filling in a questionnaire. The questionnaire has a list of open-ended questions about how feasible, useful and interesting you found the lessons introduced to you during the workshop. The completion of the questionnaire would need about 30 minutes and you have to make sure that you turn in the questionnaire to me right away and before you leave. During the following week I will contact you and arrange a meeting time for a follow up interview. The interview would take place at your school, would last about 30 minutes and would be audio recorded. The interview questions would be related to the responses that you had provided on the questionnaire.

You are expected to participate in the workshop actively, as well as fill in the questionnaire and answer to the interview questions to the best that you could. Participating in this research project would not cost you anything. The workshop would be a free professional development opportunity for you and you may use any resource that I provide you at the workshop in your science classroom. There are no potential risks for being involved in this research project. I hope that the information I get from this study would help me revise my NOS lesson as well as the Ct-NOS framework.

You are under no obligation to participate in this study. The participation is completely voluntary. You are also not obliged to answer any specific questions even if participating in the study. You may opt out without penalty and may ask any collected data withdrawn from the data base and not included in the study. The latest you could withdraw from the study is within 3 days after the interview. You have to advise me in writing that you wish to opt out. You also have to advise in writing that you wish part or all collected data to that point to be withdrawn. In that case I ensure you that I would discard the data collected from you. The questionnaire that you had filled out would be shredded and the audio record would be deleted.

I also ensure you that all data collected from you will be used only for academic purposes. The results would appear in my doctoral dissertation, as well as in scholarly publications, academic conferences, etc. Your personal information including your name, school name and contact information would remain anonymous. I will remove all identifying information from the data right after data collection is complete and will use a code system instead. All data will be kept confidential at all stages of this research and my supervisor and I would be the only people who would have access to them. Data from the questionnaires will be scanned and together with the audio records would be stored electronically in password protected files. After the completion of the research project, all data would be stored for 5 years in a password protected flash memory stored in a locked cabinet. After 5 years all data would be destroyed in a way that ensures privacy and confidentiality. You may advise me to receive a copy of the report of the research findings by sending me an email and I would be happy to share with you a copy of the report when it is ready. I may use the data I get from this study in future research, but if I do this it will have to be approved by a Research Ethics Board.

If you have any further questions regarding this study, please do not hesitate to contact me or my supervisor. Our contact information appears at the start of this letter. The plan for this study has been reviewed for its adherence to ethical guidelines and approved by Research Ethics Board 1 (REB1) at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the REB1 Chair at (phone). This office has no affiliation with the study investigators.

Thank you for your cooperation.

Best regards,

Hagop A. Yacoubian
Ph.D. Candidate

Appendix H

QUESTIONNAIRE

Name ____

Gender __________________ **Year of birth** __________________

Mailing Address

____

Telephone numbers: Landline ______________ **Mobile** ______________

Email address

____

Alternative email address (if any)

____

Name of School(s) where you currently teach

____

What subjects do you teach?

____

How many years of teaching experience do you have at the secondary level? (grades 10,11,12)

____

How many years of teaching experience do you have in total?

____

Do you hold a bachelors degree or an equivalent? If yes, please indicate your major emphasis (minor if available) and the name of the institution from where you have been granted your degree.

____

____

Do you have a teaching diploma or an equivalent certificate? If yes, please indicate the name of the institution from where you have been granted the diploma/certificate, as well as your area (science, math etc..) and level (elementary, secondary etc..) emphasis.

____

____

Please indicate any other degrees that you hold, area(s) of specialization, and the name(s) of the institution(s) from where you have been granted your degree(s).

____

Questions 1 to 4 relate to the *feasibility* of the NOS lessons that you were introduced during the workshop. Please comment on each question to the best that you could. You may use the backside of the questionnaire if you need additional space.

1. To what extent do you find the lessons feasible to be included in a secondary level science course?

2. In your opinion, what are some features of the lessons that make them feasible?

3. In your opinion, what are some features of the lessons that make them non-feasible?

4. What recommendations do you have to make the lessons more feasible?

Questions 5 to 11 relate to the *usefulness* of the NOS lessons that you were introduced during the workshop. Please comment on each question to the best that you could. You may use the backside of the questionnaire if you need additional space.

5. To what extent do you find the lessons to be useful for your students?

6. To what extent do you think your students would find the lessons useful?

7. In your opinion, what are some features of the lessons that make them useful?

8. What features of the lessons do you think your students would find useful?

9. In your opinion, what are some features of the lessons that make them non-useful?

10. What features of the lessons do you think your students would find non-useful?

11. What recommendations do you have to make the lessons more useful?

Questions 12 to 18 relate to the *interestingness* of the NOS lessons that you were introduced during the workshop. Please comment on each question to the best that you could. You may use the backside of the questionnaire if you need additional space.

12. To what extent do you find the lessons interesting?

13. To what extent do you think your students would find the lessons interesting?

14. In your opinion, what are some features that make the lessons interesting?

15. What features of the lessons do you think your students would find interesting?

16. In your opinion, what are some features of the lessons that make them less interesting or non interesting?

17. What features of the lessons do you think your students would find less interesting or not interesting?

18. What recommendations do you have to make the lessons more interesting?

19. Do you have any general comments and/or suggestions?

Appendix I

Lesson Plan

Should Cell Phone Usage be Regulated by Law?

Goal

Make an argument that could be used to defend a position on whether or not cell phone usage should be regulated by law.

Background

There is a debate among scientists on the health effects of low-intensity electromagnetic radiations from cell phones. A number of scientists claim a relation between long term cell phone usage and the risk of developing brain tumors. Other scientists refute the possibility of such a relationship.

Learning Objectives

Overall Objective

1. Based on contradictory research reports generated by scientists, make an argument that could be used to defend a position on whether or not cell phone usage should be regulated by law.

Objectives Related to Substantive Content of NOS

1. Compare and contrast experimental studies and case control studies.
2. Develop an understanding of causal generalizations

Objectives Related to Critical Thinking Skills (and knowledge underlying these skills)

1. Critically read, analyze arguments and discuss adapted primary literature involving long-term cell phone usage and the risk of developing brain tumors
    a. Identify the issue
    b. Identify the reasons provided
    c. Identify the conclusions made
    d. Evaluate whether the reasons are sufficient to establish the conclusion(s)

e. Understand the broader context
f. Understand the background
g. Aim for clarity

2. Develop an understanding of causal generalizations and identify criteria that could be used to evaluate causal generalizations.
3. Using the criteria to evaluate causal generalizations, argue to what extent one could infer causal relationship from case control studies.
4. Analyze case control studies that study the relationship between cell phone usage and risk of brain tumors.
5. Apply your understanding of causal generalizations to evaluate the extent to which evidence supports a relationship between long term cell phone usage and risk of brain tumors.

Objectives Related to Critical Thinking Dispositions (and knowledge underlying these dispositions)

1. Care about getting the most unbiased answer that could be possibly developed in the circumstances of this lesson
2. Aim for being honest
3. Care about the worth and dignity of others
4. Develop an understanding for why these dispositions are important in critical thinking

Procedure

1. (Could be assigned as home work) Ask the students to read critically the adapted versions of Ahlbom et al.'s (2009) and Khurana et al.'s (2009) articles. Teach students how to read critically. Provide guidelines/worksheets as needed that could help students engage in argument analysis (Ennis's suggestions might be helpful). E.g. Identify the issue, identify the reasons provided, identify the conclusions made, evaluate whether the reasons are sufficient to establish the conclusion(s), research the broader context, research the background.

2. Guide the students to engage in a discussion of the articles. Ask questions as what is the issue? What are differences and similarities between the goals, methods, results and conclusions of the two groups of researchers?

What reasons do the scientists provide to support their conclusions? Etc… Guide the students to provide clear, meaningful, coherent answers and give feedback to each other.

3. Lead the discussion to a stage where students could realize the difficulties of making causal generalizations. Introduce the NOS question: In what circumstances could a causal generalization between variables be considered a strong one?

4. Ask students if it is possible to conduct controlled experiments on humans to explore the effects of long term cell phone usage on the risk of brain tumors. Help them to appreciate the fact that in such situations there are other methods that scientists use in designing their studies.

5. Provide an example of a case control study and guide students to analyze it

6. Guide the students to compare and contrast case control studies and experimental studies

7. Ask students to reflect on the example of the case control study (step 6) and think about what might be some criteria that we may use to answer the NOS question (see step 3). Cue them as needed.

8. Engage the students in a discussion and eventually introduce Ennis's criteria to support causal generalizations. [(1)The existence of a singular-causal instance of the generalization; (2) the representativeness of the instance; (3) the existence of a set of instances in which cases of the supported cause are associated with cases of the supported effect; (4) the investigator's having deliberately introduced the independent variable; (5) the plausibility of the causal chain; (6) the derivability of the causal generalization from a set of one or more broader causal generalizations or laws; (7) the assertion of the causal generalization by a credible source].

9. Ask students to apply their understanding and criteria of causal generalizations to evaluate the extent to which evidence supports a relationship between long term cell phone usage and risk of brain tumors. Every student writes down his/her evaluation

10. Engage the students in a whole class discussion to share their evaluations

11. Ask students to make arguments, based on their evaluations, that could be used to defend a position on whether or not cell phone usage should be regulated by law. Every student writes down his/her position

12. Engage the students in a whole class discussion to share their positions